A MULTI-STAKEHOLDER ABRIDGED ENVIRONMENTALLY CONSCIOUS DESIGN APPROACH

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Abstract

Environmental concerns play an increasingly important role in product design. As these concerns have mounted, so have academic and industrial research efforts into ways to reduce the environmental impact of products through approaches such as Environmentally Conscious Design (ECD). Existing research has not yet sought to understand the role of stakeholders in ECD. New ECD approaches and techniques will have to be able to adapt and interface effectively with various stakeholders in the design and development process and throughout the life cycle of a product to ensure that both single and multiple life cycle issues are considered. They will need to be able to assist in selecting a suitable life cycle strategy, analyzing designs and suggesting possible improvement methods. An exploratory multi-method research approach was chosen which involved the use of numerous qualitative and quantitative methods including surveys (questionnaires and informal interviews), industrial case studies and a focus group. The research explored the role of stakeholders in ECD, and developed a new methodology for integration of a novel stakeholder 'body of knowledge' through an abridged life cycle approach. It showed how ECD relies on the close co-operation and input of many different stakeholders both within and external to a company. The 'body of knowledge', a set of criteria representative of stakeholder views and opinions, had been gathered from a range of stakeholders over the life cycle of a number of electromechanical products and their packaging. The 'body of knowledge' is of global benefit with the data and weightings having the potential to be modified for different products. It also has the potential to be continually updated through consultation with other stakeholders and further case studies. The approach is based on an analyze-report-prioritize-improve framework and utilizes a clearly defined step-by-step procedure for assessing, scoring and subsequently reducing, the environmental impacts of products with single or multiple life cycles. It uses techniques such as life cycle strategy worksheets, flow diagrams, and matrices, with predetermined environmental categories, profiling, tailor-made guidelines and checklists. The approach contains an in-built mechanism for incorporating stakeholder requirements and strategies in the process. The paper-based 'Multi-Stakeholder Abridged ECD Approach' is quick and easy to use and of

immediate value to the company with stakeholder participation and co-operation the key to its success. It ensures that multi-criteria value judgements are not based on an individual assessor, but a group of stakeholders, the Life Cycle Team members, who participate at predetermined stages of the ECD process. The data is generalized for a range of electromechanical products. The approach can be implemented as part of a Green Concurrent Engineering process, for re-designing an electromechanical product and its packaging or comparing alternative designs.

In summary, in fulfilling the research needs the thesis presents an original contribution to knowledge in the field of ECD through the development and validation of a novel abridged ECD approach. The thesis also identifies areas of further work that will increase the knowledge base, scope and applicability of the work carried out.

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Abbreviations

CE	Concurrent Engineering
CFT	Cross-Functional Team
DfA	Design for Assembly
DfD	Design for Disassembly
DfE	Design for Environment
DfR	Design for Recycling
Df'X'	Design for 'X' ('X' is the requirement such as assembly and quality)
ECD	Environmentally Conscious Design
ECDM	Environmentally Conscious Design & Manufacture
ECO2-IRN	Ecologically & Economically Sound Design & Manufacture - Interdisciplinary Research Network
ECTEL	European Trade Organization for the Telecommunication and Professional Electronics Industry
EOD	Environmental Objectives Deployment
EOL	End-Of-Life
EPD	Environmental Product Development
EPP	Environmental Performance Profiling
ERP	Environmentally Responsible Product
FMEA	Failure Modes and Effects Analysis
FP1, FP2, FP 3	Finishing Process 1, 2 and 3 respectively.
GCE	Green Concurrent Engineering
ICER	Industry Council for Electronic Recycling
LCA	Life Cycle Assessment
LCT	Life Cycle Team
MET	Materials, Energy, Toxicity
MLC	Multiple Life Cycle
OA	Office Automation
PO	Escape Provocation
QFD	Quality Functional Deployment
RLCA	Reverse Life Cycle Assessment
SA	Sub-Assembly
SAW-method	Simple Additive Weighting-method
SLC	Single Life Cycle
TG	Tollgate
TWS	Total Weighted Score
TWR	Total Weighted Rank
WR	Weighted Rank
WS	Weighted Score

Definitions

Abridged Life Cycle Approaches

'Abridged Life Cycle Approaches' maintain the fundamental essence of quantitative Life Cycle Assessment (LCA), in analyzing the full life cycle. However, due to their qualitative nature they require less time to carry out and do not require collection of vast quantities of data.

'Body of Knowledge'

The 'body of knowledge' is a set of environmental criteria representative of key product stakeholder views and opinions, that is gathered from a range of product stakeholders over the life cycle of a number of electromechanical products and their packaging. It consists of the criteria that these key product stakeholders consider important in evaluating designs.

End-of-Life Asset Management and End-of-Life Asset Managers

'End-of-life (EOL) Asset Management' involves choosing the optimum route for a product at EOL. An EOL asset manager is the term applied to the people who undertake the task of gaining the maximum value from a product, with the minimum possible impact on the environment.

Environmentally Conscious Design

Environmentally Conscious Design (ECD) follows a 'life cycle thinking' approach, taking consideration of environmental impacts throughout the life cycle of the product. It is typically defined as a management approach where environmental quality is considered systematically alongside cost and other performance standards. The aim is to develop environmentally compatible products and processes while maintaining or improving price, performance and quality standards.

Green Concurrent Engineering

In Green Concurrent Engineering (GCE) companies adopt strategies and methods for ECD at the design stage.

Life Cycle Team

In Green Concurrent Engineering (GCE) a Life Cycle Team (LCT) enables close co-operation with external life cycle stakeholders. The LCT is used to acquire comprehensive knowledge about the product system and to present an image reflecting the product life cycle and the stakeholders involved.

Multiple Life Cycle Product

A multiple life cycle (MLC) product can be simply defined as one that is given multiple lives through techniques such as remanufacture, reuse and recycling.

Product Stakeholders or Stakeholders

Throughout the life of a product numerous people can influence its performance. These people are more commonly knows as 'product stakeholders' and can be defined as people who are affected by, and influence many facets of a products life cycle, including its environmental impact. Product stakeholders, or simply stakeholders, include manufacturers, users, distributors, service engineers, asset managers and government and opinion-formers. Stakeholders can be divided into two groups; major and minor and may be internal, based within the company, or external to the company.

Single Life Cycle Product

Single life cycle (SLC) product types can be loosely defined as those that follow linear, sequential stages through their life cycle until they reach final disposal.

Sustainable

Product features that consider the needs of the present without compromising the ability of future generations can be termed 'Sustainable'.

1 Introduction

This chapter provides an introduction to the research topic. The research explored the role of product stakeholders in Environmentally Conscious Design (ECD) and provided a methodology for integration of a product stakeholder 'body of knowledge' through an abridged life cycle approach. The chapter gives a brief overview of the design process, green concurrent engineering, product stakeholders, design for 'X' approaches, and the integration of environmental considerations into the design process. Current ECD terminology is outlined and a working definition for ECD provided, along with an introduction to single life cycle (SLC) and multiple life cycle (MLC) products, and traditional and abridged life cycle approaches. The main problems with current abridged approaches are outlined, along with the purpose of the research and the main objectives and deliverables. The chapter concludes with a brief description of the structure of the thesis.

1.1 The Need for Environmentally Conscious Design

The products that people design, manufacture and use cause the vast majority of today's environmental problems in one way or another. Designers need to play an active role in reducing these problems through consideration of environmental considerations over the product's life cycle. Traditionally designers had been concerned only with criteria such as function, appearance and cost. Concern for environmental protection, and increased legislation has led to a need to design and manufacture environmentally sound products. The notion that designers can influence the environmental impact of products and processes through integrating environmental considerations into the design process is by no means a new one. Thirty years ago Victor Papanek urged designers to resist built-in obsolescence, address consumers needs and not their wants, and find ways of using their skills for socially useful ends (Papanek, 1971). This viewpoint, which outraged many design establishments in 1970, is now relevant and inevitable (Holloway *et al.*, 1994). In the 1980's, initiatives such as the 'Bruntland Report' and ever increasing scientific evidence of global warming, ozone depletion and acid rain led to new legislation and guidelines emerging, banning the use of such ozone depleting substances as chloro-flurocarbons (CFC's) and encouraging the production of recyclable products and packaging. With the increasing demand on industry to produce environmentally conscious products at lower costs, the early 1990's and onwards have seen an increasing amount of activity in companies and research around the subject of ECD. Companies are currently being faced with recycling regulations, impending product take-back[1], and other legislation, forcing them to analyze and reduce the environmental impact of their products and processes. Other factors pushing companies include corporate image, public perception, consumer demand, the need to maintain competitive advantage and the rising costs and associated environmental damage of waste disposal. Dewberry (1996) found the main drivers for considering environmental issues in the design process to be legislation, cost, philosophy and suppliers, while including environmental criteria within the design brief increases the challenge for the designer and therefore encourages a greater degree of creativity. Reducing the associated environmental burdens of products and processes represents a significant challenge to designers, manufacturers and other participants in the products life cycle. Successful ECD must consider how to achieve the long-term vision of a sustainable society where radical changes in behavior and reductions in consumption are essential. Sweatman & Simon (1996) stated that in order to achieve sustainable development we need to reduce our consumption of resources and energy by a factor of 20 by the year 2040. This equates to a reduction to 5% of current levels. Taking factors such as population growth and longer life expectancy into consideration this figure may still be a long way from sustainability. As Holloway (1997) stated, we must always try and move towards sustainability, but never believe that we are there. Designers have a crucial role to play in achieving a more sustainable society. For designers to play an active role in achieving this vision of sustainability, a long-term vision of the design of products or processes is required. Ryan (1998) promotes dematerialization, service-products, product life extension and product or component cycling as possible strategies for achieving this factor reduction. Economic,

[1] Proposed European Directive on Waste from Electrical and Electronic Equipment (WEEE) due in 2003.

social and ethical issues are raised when studying environmental issues. The constantly changing attitudes and behavior of consumers make the role of the designer even more complex. Predicting consumer behavior in the short term is difficult enough but in the long term products designed today will have to accommodate consumer behavior in future years. It is an absolute requirement that ECD takes a whole life view of a product if we are to effectively use the design effort (McAloone and Evans, 1995). Designers must grasp this concept fully to design truly environmentally conscious products and move towards a sustainable future as they have the greatest influence over every aspect of the life of the product, from design and manufacture through to usage and disposal. ECD demands consideration of different criteria and weightings to traditional design. There are new concerns such as the suitability of a product for recycling at end-of-life (EOL) and accounting for the views of product stakeholders, such as EOL asset managers, who are outside of the traditional design team. Successful environmental analysis requires the designer to balance environmental considerations, such as ease of disassembly and recycleability, with traditional considerations such as quality and performance. It also requires working closely with product stakeholders over the full life cycle. Academia and industry alike have spent much effort on creating new tools and techniques to solve these environmental problems, many of which are outlined in Sweatman & Simon (1996). The need for research into environmentally conscious design has been documented in numerous recent research reports including, Dewberry (1996), Holloway (1997), and McAloone (1998). To date however, little attention has been paid to the way in which product stakeholders should be involved in ECD.

1.2 Focus of Thesis

From the literature review it will be seen that there is a need to pay particular attention to the role of product stakeholders in ECD. The thesis focused on the role of product stakeholders in an abridged ECD process for electromechanical products and their packaging. The research critically examined existing abridged approaches and identified that the role of product stakeholders had not been clearly explored or defined. There had been some recent work but this was limited in nature as the 'body of knowledge' did not evolve from the views of a range of product stakeholders (Lundie and Huppes, 1999). There had been no published work outlining a comprehensive product stakeholder 'body of knowledge' for an abridged life cycle approach. For the purpose of this thesis, this 'body of knowledge' is defined as a set of environmental criteria representative of key product stakeholder views and opinions, that is gathered from a range of product stakeholders over the life cycle of a number of electromechanical products and their packaging. It consists of the criteria that these key product stakeholders consider important in evaluating designs. By drawing on a series of surveys, case studies and a focus group the work resulted in a 'body of knowledge' which was applied in an abridged ECD approach.

1.2.1 Choice of Product Group

Electromechanical products and their packaging contribute to processes that increase atmospheric pollution, destroy the ozone layer, pour toxic chemicals into the water, and create millions of tons of solid waste that cannot be recycled. This product group was selected for the research for the following reasons:

- The electromechanical industry sector has been highlighted as an area of great environmental concern worldwide. As such, electromechanical waste has been classified as a priority waste-stream in Europe. Existing and emerging legislation is affecting the way in which these products are designed, manufactured and dealt with at their EOL. Packaging legislation which is currently in place includes the 'Producer Responsibility Obligations (Packaging Waste) Regulations 1997' which came into effect in the U.K in January 1999. These regulations implement a European Directive that requires member states to ensure that a proportion of their packaging that ends up as waste is recycled. The 'Packaging (Essential Requirements) Regulations 1998' introduced at the end of May, 1999 require minimization by setting down the minimum requirements for packaging which is to be placed on the market.
- The author had worked for four years prior to the research in a design team developing one family of electromechanical products, personal computer and peripheral devices (PCs),

and thus had extensive background design knowledge in this area. This greatly facilitated the research.

- With the author's background experience it was possible to attract industrial collaboration from a number of companies including Alps Electric (Ireland) Ltd. (Alps), Matsushita Electric (U.K.) Ltd. (Panasonic), Sony Manufacturing (U.K.) Ltd. (Sony), and Apple Computer (Ireland) Ltd. (Apple).

1.3 The Product Design Process

The product design process can be systematically divided into phases that have various names in literature but possess conceptually the same content, Figure 1-1. In accordance with these phases in design, a number of tasks must be carried out by various functions in the company.

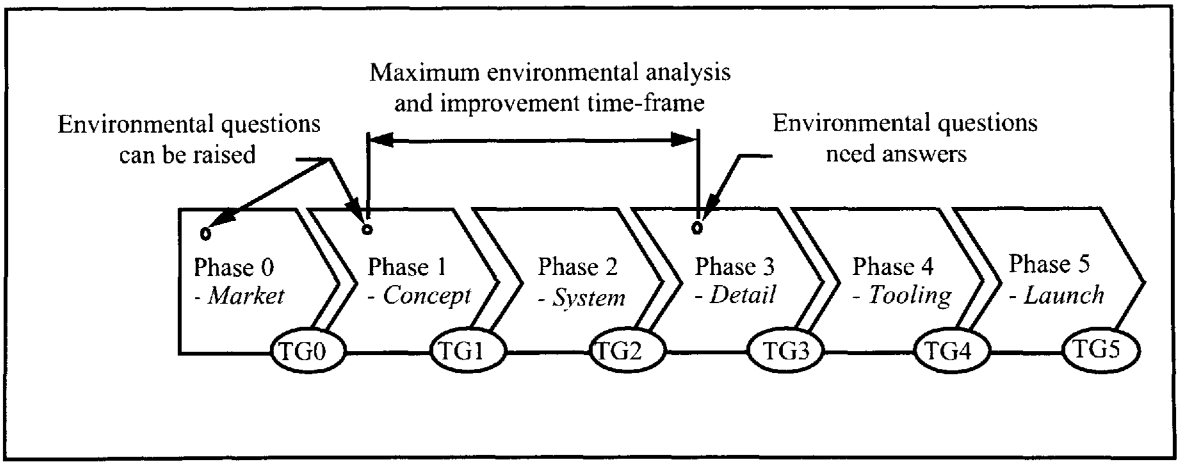

Figure 1-1 Product Design Process (Adapted from Karlsson, 1997)

The most active functions are design, engineering, production and marketing. However, purchasing, finance, service and other functions should also become involved. The total of all these activities comprises the product design process. Pugh (1991) describes the design process using a total design activity model. It includes a design core enveloped by the product design specification with inputs from technology/discipline independent and dependent methods and sources. The design core activities are operated iteratively

The extent of environmental effects is largely determined by decisions taken during the product design process (Roozenburg and Eekels, 1995). Upwards of 70% of a products manufacturing cost are determined at the design stage so it can be assumed that a large portion of the environmental costs are also dictated at this stage. It has also been shown that even though product design constitutes only 5% of the total cost of a product, the designs influence on the product cost can be up to 70% (Holloway *et al.*, 1994). Successful product design requires the inclusion of all the environmental concerns at the design stage. McAloone *et al.* (1998) found that pre-specification environmental design changes have a greater impact on the product and the later you introduce ECD in the design process the harder it is to affect the environmental profile. They also found that it was imperative to include marketing in early design so they would understand the need for ECD (McAloone *et al.*, 1998). Designers need techniques that will enable them to analyze the environmental concerns of alternative candidate designs and make radical improvements before the detail design stage. Due to constraints such as cost and time, it is only possible to make incremental improvements after the detail design stage.

1.4 Concurrent Engineering

In Concurrent Engineering (CE), activities within all functions are organized in parallel using a cross-functional team (CFT). The product design process is iterative, and the sequence of phases is not considered as rigid. As a control mechanism to ensure that the project is running correctly, tollgates (TG) are introduced at critical points in the process, most likely between the design phases. The main goals of CE have been to decrease time-to-market and project costs while improving product quality. This has required balancing quality with other key requirements such as performance, aesthetics, product cost and, more recently, environmental considerations. A CFT enables close co-operation with external life cycle stakeholders and creates an organization with knowledge of the product life cycle in total (Karlsson, 1997).

1.5 Green Concurrent Engineering

In Green Concurrent Engineering (GCE) companies adopt strategies and methods for ECD at the design stage. A CFT is again used to gain comprehensive knowledge about the product system. In this situation a team of 5-6 people is selected to present an image reflecting the product life cycle and the product stakeholders involved and is termed a Life Cycle Team (LCT). The fundamental ideas behind GCE and a LCT are summarized in Karlsson (1997).

1.6 Product Stakeholders

Throughout the life of a product numerous people can influence its performance. These people are called 'product stakeholders' and can be defined as people who are affected by, and influence many facets of a products life cycle, including its environmental impact. Product stakeholders, from herein known simply as stakeholders, can also be known as life cycle participants and include manufacturers, users, distributors, service engineers, EOL asset managers, government and opinion-formers, Figure 1-2. The role of a selection of life cycle participants in ECD has been identified (Keoleain and Menerey, 1993). Stakeholders can be divided into two groups; major and minor (Smith and Haines, 1995). For the purpose of this research, major or key stakeholders are those who have a direct influence on a product's environmental impact and include designers, manufacturers, and users. Minor stakeholders have a minimal influence on the products environmental impact and can include finance personnel and the general public. Stakeholder groupings may vary from company to company and product to product. Stakeholders may be internal, i.e., a designer based within the company, or external, i.e., a component supplier to the company. This stakeholder definition is different in nature to the stakeholder definition used by organizations such as Greenpeace, which refer to all the inhabitants of the earth.

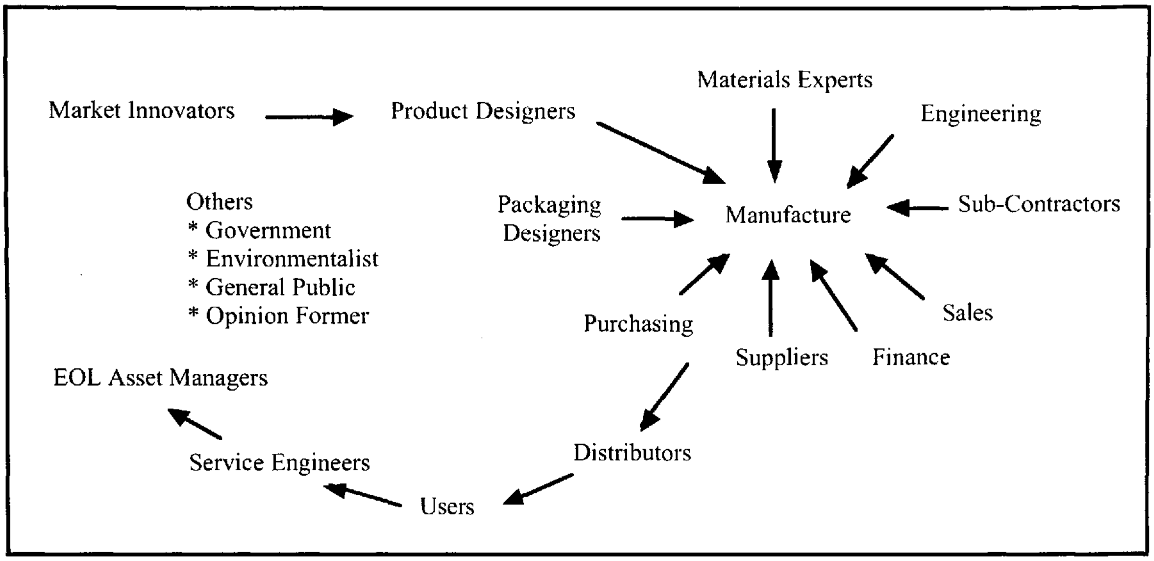

Figure 1-2 Simplified Diagram of Product Stakeholders

A simplified breakdown of the stakeholders can involve five main groupings, Table 1-1. All stakeholders involved in the production and delivery of the product to the user are included in one group, termed 'Producers'.

Table 1-1 Stakeholder Groupings

Stakeholder Grouping	Members
Government	Includes government policy makers.
Producers	Includes designers, manufacturers, distributors, etc.
Users	Includes general public.
Environmentalists	Includes environmental experts.
Others	Includes service and EOL asset managers.

1.7 Design for 'X' Approaches

To produce a successful product design the CFT must consider a range of key requirements. The traditional way to consider these has been to take a Design for 'X' approach (Df'X'), where 'X' is the requirement such as assembly, manufacture, quality, reliability and performance. Several Df'X' methodologies have been developed for including key requirements in the design process. One of the most successful to date has been the Design for Assembly (DfA) system by Boothroyd and Dewhurst (1997), which consists of a 'body of knowledge' and a methodology for applying this knowledge to evaluate and compare designs. The DfA system acknowledges that there are many possible solutions, and that the most appropriate depends on a range of requirements. By requiring judgements to be made on the economic implications at each stage of the design process, the user is successfully guided towards an optimum solution (Boothroyd and Dewhurst, 1987). Successful implementation of DfA advocates a team approach in which all involved parties are represented, and where judgements can be made with minimum delay and iterations (Redford and Chal, 1994). The need for Df'X' methodologies arises from the fact that designers cannot be expected to be subject experts on every factor that arises during the design process. Some environmental considerations have been treated in a Df'X' manner including disassembly and recycling. Design for Disassembly (DfD) involves developing products that are easy to take apart. This facilitates recycling and removal of hazardous materials. Dowie (1995) explored DfD in detail and presented a methodology to ensure that products can be designed to be attractive for recycling at EOL. Chiodo *et al.* (1998) developed shape memory alloy actuators in a wide variety of consumer electronic products to facilitate active disassembly. Design for Recycling (DfR) is closely linked to DfD. DfR recognizes that eventually every product will eventually wear out or become obsolete, and therefore every effort should be made to reduce the amount of waste to landfill, through recycling the constituent materials. DfR approaches include reducing the number of different materials used, replacing toxic materials with non-hazardous alternatives, and reducing product complexity.

1.8 Df'X' and the Environment

Df'X' considerations relate to different stages of the design process (McAloone, 1998). Df'X' is sufficient for considerations that occur at specific stages in design; Df'D and DfR should occur at the concept stage. However for other facets of ECD, such as reuse of components over multiple product life cycles, Df'X' is not sufficient. Component reuse affects every stage of the product's life and can not be addressed at merely one specific point in the design process. Environmental considerations are generally much more complex than other Df'X' requirements, and designing for the environment is not an extension of the Df'X' approach. Environmental considerations require a new set of decision-makers, the LCT, to be involved with design decisions. The designer must consider environmental considerations as an integral part of every stage in the design process. The links between Df'X' imperatives are outlined in Holloway (1997).

1.9 Eco-Terminology

The past few years have seen a growing catalogue of terms to describe approaches to integrating environmental considerations into the design process. The approach adopted here, ECD, is very similar in practice to the application of life cycle thinking behind the approaches of 'Eco-design'; 'Environmentally Conscious Design & Manufacture' (ECDM); 'Design for the Environment' (DfE), 'Life Cycle Design' and 'Green Design'. These terms are typically defined as management approaches, where environmental quality is considered systematically alongside cost and other performance standards. The aim is to develop environmentally compatible products and processes while maintaining or improving price, performance and quality standards. Although these terms are largely interchangeable and have many of the same goals, there are some differences in meaning between the different titles. These differences are detailed in Dewberry (1996), Holloway (1997) and McAloone (1998). A useful distinction can be made however between the concept of ECD and the practice of 'Sustainable Design', which aims to develop products whose production and use is demonstrably sustainable. Adopting the ECD approach has typically lead to the incremental improvement of existing products which does not challenge the status quo of society (Simon and Sweatman, 1997). Sustainable products are typically more radical and embody more directly the principles of sustainable development, both physically and conceptually. Simon and Sweatman (1997) state that sustainable products must generate capital for future generations to offset their use of non-renewable resources. Sustainability is more a direction than an action and is seen as being the ultimate goal; everything we consume goes complete circle, is renewable and has a further use. This is the boundary within which sustainable design fits (Holloway, 1997). One of the key elements of sustainable product development is a stakeholder-oriented approach (Charter cited in Dewberry, 1996). As well as setting certain guidelines for a world 'clean-up', the Bruntland report laid down a definition for the term 'Sustainable Development' (Bruntland, 1987):

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Another important term is 'Industrial Ecology'. Graedel and Allenby (1995) describe industrial ecology as 'the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution'. The concept requires that an industrial system be viewed in concert with its surrounding systems. It is a systems view in which one seeks to improve the total materials cycle from virgin material through to ultimate disposal. Factors to be improved include resources, energy and capital. Designers can play a part in industrial ecology by considering the future uses of the products they design (Graedel & Allenby, 1995). Finally 'Eco-efficiency' is where service concepts contribute to both economic and environmental efficiency. Three typical service concepts have been identified. Product-oriented services make very little use of institutional arrangements and interaction and often only address one very specific point. Use-orientation is where the material product is not sold and the client only pays for its use. Need orientation goes beyond any product barriers and delivers a service that is not bound to a particular product (Hockerts cited in Charter and Polonsky, 1999).

1.10 Environmentally Conscious Design

ECD follows a 'life cycle thinking' approach, taking consideration of environmental impacts throughout the life cycle of the product, both up and downstream of a products use, without unduly compromising other criteria like reliability, performance, cost and aesthetics. The environment is considered inherently at each stage of the design process. ECDM is the progression of ECD along the design model into the manufacturing process. Design of products also affects the manufacturing process, and ECDM should consider the environmental impact of product designs on their production processes.

1.11 Extension of Jakobsen's Design Model

ECD is no different to any other design strategy in that there are a number of trade-offs that have to be made when considering the design as a whole. Holloway *et al.* (1994) extended Jakobsen's traditional model of the basic interrelationship between different design requirements to include environmental considerations. In the same way that function, material, shape and production methods are all interdependent they also have influence on, and are influenced by, environmental concerns. In the extended model environmental concerns are not directly related to all the other elements in design. There are strong direct relationships between environmental impact and function, material and production method. There is, however only an indirect link between environmental concerns and shape, and this indirect link is affected by material, function and production method. Presenting the integration of environmental concerns in this manner allows us to see how they affect other decisions on a basic level.

1.12 Product Life Cycle

Designers traditionally have only considered SLC products. These product types are loosely defined as those that follow linear, sequential stages until they reach final disposal (O' Connor and McLaren, 1997). These stages fall under three main headings: primary processing phase (stages before product design), users perceived life phase (stages from design to retirement), and EOL phase (disposal stage). Each of these phases has a variety of sub-phases, and within each of those, environmental considerations ranging from energy efficiency to the creation of hazardous by-products must be considered. The usage life span of these products can vary significantly. Some estimated average life times for typical electromechanical products are provided in (Kostecki, 1998).

Table 1-2 Typical Product Life Times (Adapted from Kostecki, 1998)

Product	Life Time (Years)
Cookers	10-15
Microwave Oven	8-10
Personal Computer	3-5
Refrigerator	8-12
Telephone	4-6
Television	8-10
Washing Machine	7-10

1.12.1 EOL Reasons

Many electromechanical products are not obsolete when they reach EOL retirement. Products can be retired for many reasons, Table 1-3 (Adapted from Kostecki, 1998). These reasons are usually not static and can vary from year to year, generation to generation. Consideration on how product life spans can be extended, or on how they can be recovered more efficiently, is required. Recently Nortel developed a telephone that allowed the customer to upgrade the unit without having to buy a new one and scrapping the old one. The design minimizes product obsolescence and reduces the volume of product headed for recycling or disposal (Kostecki, 1998).

Table 1-3 Reasons for Shorter Product Lives (Adapted from Kostecki, 1988)

No.	Reason
1	Ever-increasing production favors less durability.
2	Managerial decision-making is biased towards single use.
3	Consumers have a preference for novelty.
4	Consumers are manipulated to consumer faster.
5	Rise in per capita income reduced consumer's concern with optimal use of products.
6	Product/service price ratio has changed to the disadvantage of the repair service and has reduced the life of products. The cost of repair may be higher than cost of replacing the product.
7	Technological progress continues to render products obsolete, for example, upgrading of product families resulting in compatibility problems, or new advances highlight shortcomings of products and customers phase out usage.
8	Difficulty in communicating the benefits of durability to the consumer.
9	Most used products have an image problem.
10	The systems of retake, re-marketing and re-manufacturing tend to be archaic and ineffective.

1.13 Multiple Life Cycle (MLC)

The ideal situation is to reduce the need for a product, component or material. Otherwise, products, components and materials can be given multiple lives by remanufacture, reuse and recycling, Figure 1-3. These MLC products save resources and reduce waste generation, although the quantities involved vary considerably from industry to industry.

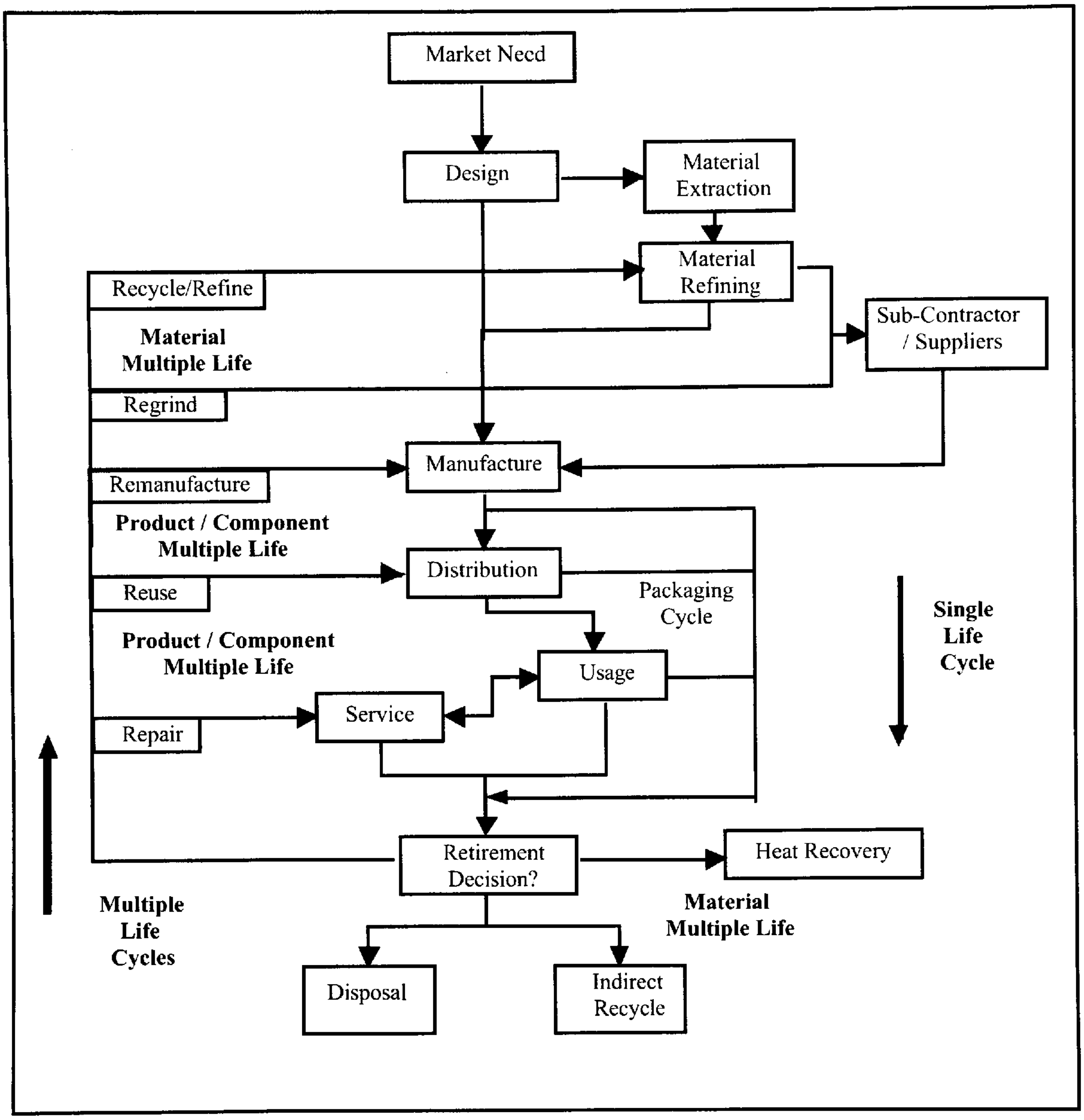

Figure 1-3 Simplified Single and Multiple Life Cycles

This MLC definition takes a simplistic view. Ideally, the life cycles of replacement components and materials used during the collection and remanufacture/reuse stage also need to be accounted for. The definition introduces extra process considerations, uncertainty due to an extended time-scale and implications for control of product usage and disposal. Designers now need to take into account considerations such as designing products for rapid safe sorting, disassembly, and cleaning processes (O' Connor and McLaren, 1997).

1.14 Life Cycle Assessment

A popular method of assessing the environmental impacts of a product throughout its life cycle is known as Life Cycle Assessment (LCA). LCA entails the detailed analysis of all the material, energy and toxicological inputs and outputs related to a product over its life cycle. Although a great deal of research has been carried out in this area, LCA still remains of little value to designers; it takes too long to execute and results are often difficult to interpret. Results are also very dependent on where the analyst chooses to draw the system boundary. To date, where LCA has been used to compare the environmental impact of similar products, results have been inconclusive (McAloone, 1998).

1.15 Abridged LCA

A number of companies have developed abridged LCA approaches: most notably AT&T, and Motorola (Graedel and Allenby, 1995, Hoffman, 1995). Abridged LCA maintain the fundamental essence of quantitative LCA, in analyzing the full life cycle, but due to their qualitative nature they do not require collection of vast quantities of data. One common abridged approach involves using a matrix to help the designer focus on key environmental considerations (Graedel *et al.*, 1995). Qualitative and quantitative data inserted within the matrix may be scored using an appropriate scoring system that may be adjusted to suit the particular purpose. The outcome aims to highlight areas in the products life cycle with the greatest environmental impacts, and hence pinpoint priorities for further design effort to decrease these impacts. Abridged LCA techniques require less time to carry out than a traditional LCA and are less data-intensive. Many companies have successfully adopted abridged techniques, including matrix evaluations, and experience demonstrates that LCA for a complex product works most effectively when it is performed semi-quantitatively and in modest depth.

1.16 Problem Statement

The design of environmentally sound electromechanical products and packaging involves an enormous effort for a designer. Design tools and techniques need to be appropriate for different stages of the design process and need to consider the many constraints, such as ever shortening product development times. They need to be able to assist in selecting a suitable life cycle strategy, analyzing designs, and suggesting possible improvement methods. An abridged life cycle approach was chosen for this research. LCA directs the current ECD thinking and has the potential to become a simulation tool in the hands of the designer, and a policy instrument for authorities (Roozenburg and Eekels, 1995). Abridged tools enable the analysis of traditional design requirements, such as performance and reliability, alongside environmental considerations, such as recycleability and energy consumption. These tools can be used by designers for assessing, and reducing, a products environmental impacts over its' full life cycle, from extraction through usage to EOL. Designers have experimented with these methods and have found their more qualitative approach useful to adopt, albeit with some concerns raised over the quality of decision. Abridged LCA depends on the experience and knowledge of the user, thus the total score is affected by the user's subjective decisions, utility, experience and knowledge (Chen, 1995). An important methodical problem is weighting dissimilar environmental effects against each other. Which product is less harmful: a product that consumes less energy, but produces a lot of waste, or a product with opposite effects? Value judgements are required to decide the relative weighting of the multi-criterion. Weighting environmental considerations is further complicated when the 'decision maker' is not an individual, but a heterogeneous group of stakeholders, who do not pursue the same goals (designer, government, consumer etc.) (Roozenburg and Eekels, 1995). Up to now, abridged approaches have failed to examine the role of stakeholders in SLC and MLC products. This research develops a novel abridged approach, which uses quantitative data, where available and qualitative data collected from key stakeholders. Stakeholders should have a role in determining key design criteria, including the identification and weighting of key environmental considerations. The new abridged approach should include a procedure for selecting a suitable life cycle strategy for the product. Selecting a suitable life cycle strategy for a product is an extremely onerous exercise, which should be carried out as early as possible in the design process. Key decisions are required on the product need, its life span and what functions and features to include. The LCT needs to determine whether it should have a SLC or MLC, and what to do with it when it becomes finally obsolete. This requires detailed information and knowledge that many companies, especially small and medium sized enterprises (SMEs) do not have the time, money or resources to attain. For example, service personnel should be consulted on issues such as product repair and part replacement while EOL asset managers should be consulted on the optimum ways of recovering or disposing of products.

This study examines the role of stakeholders in ECD using abridged approaches and develops a new ECD methodology. By drawing on a series of surveys, case studies and a focus group, the research results in a set of criteria representative of stakeholder views and opinions – a 'body of knowledge'. These are the criteria that stakeholders consider important in evaluating designs. Using this 'body of knowledge' an abridged approach was then developed for SLC and MLC products. The approach consists primarily of a life cycle strategy worksheet, input-output flow diagrams, an environmental category matrix, profiling, checklists, and creative-thinking tools. It was developed to analyze, score and improve designs.

1.17 Research Objectives

The following objectives were set at the start of the study:

To gather a 'body of knowledge' from a range of key stakeholders in the life cycle of electromechanical products and their packaging that primarily consists of the most important environmental considerations categorized. The 'body of knowledge' should also include a list of guidelines for selecting a suitable life cycle strategy, along with other generic ECD guidelines. It will be gathered using surveys, case studies and a focus group.

To develop and test a methodology for incorporating this 'body of knowledge' into an abridged ECD process.

1.18 Research Deliverables

The following deliverables were set at the start of the study to arrive at the 'Multi-Stakeholder Abridged ECD Approach':

A 'body of knowledge' from a range of key stakeholders for electromechanical products and their packaging.

A methodology for integrating this 'body of knowledge' into an abridged ECD process.

The research applies a novel approach in using stakeholders, through surveys, case studies and a focus group, to develop the 'body of knowledge' for an abridged ECD approach. The 'body of knowledge' consists of an extensive list of categorized environmental considerations, generic ECD checkpoints, along with a list of guidelines for selecting a suitable life cycle strategy, for the product and its packaging. Qualitative data is based on stakeholder views and empirical data. Using this information the designer or abridged ECD assessor is able to weight dissimilar environmental effects, such as energy consumption and disposal considerations, against each other to clarify which product design is less harmful. The 'body of knowledge' ensures that multi-criteria value judgements are not based on the individual designer or abridged ECD assessor, but a group of stakeholders. The data is generalized for a range of electromechanical products and their packaging. In parallel, the tool utilizes a methodology consisting primarily of a life cycle strategy worksheet, input-output flow diagrams, and an environmental category matrix, profiling, checklists and improvement techniques. In terms of originality the research work resulted in an ECD methodology which:

- takes account of the views of key stakeholders over the life of a range of electromechanical products – a multi-stakeholder approach
- takes account of SLC and MLC considerations, while considering the optimum life cycle strategy at the design stage
- uses both quantitative and qualitative generic data
- is of global benefit with the data and weightings having the potential to be modified for different electromechanical products
- has the potential to be continually updated through consultation with stakeholders and further case studies

The methodology can be implemented as part of a GCE process. It looks further than the short-term goal of profit orientation to force designers to take into account a wider range of stakeholder considerations for multiple lives. At present there are no methodologies available that have this potential, thus demonstrating the originality of the research.

1.19 Thesis Structure

The structure for the remainder of this thesis is:

Chapter Two	This chapter critically reviews the literature and identifies the research need.
Chapter Three	The research methodology that was chosen to satisfy the research aims is described in this chapter.
Chapter Four	This chapter presents and discusses the pilot study research results.
Chapter Five	This chapter outlines and reviews the main study research results.
Chapter Six	This chapter outlines and validates a new abridged ECD approach.
Chapter Seven	The final conclusions for the thesis are presented.
Chapter Eight	This chapter provides some recommendations for further research.

The next chapter provides a critical review of the literature in this field.

2 A Critical Review of the Literature

This chapter critically explores the approaches to ECD that have been developed over the past years. Starting by investigating the eight main approaches, through to the development of analysis and improvement tools, an understanding will be demonstrated of what constitutes 'state-of-the-art' in the field. Through a critical review of the literature, and consultation with industry and academia, limitations in the current abridged approaches are identified. These form the basis of the need for the research that is presented in this thesis.

2.1 ECD Approaches

In recent years, a number of tools and approaches have been created to facilitate the inclusion of environmental considerations in the product design process. The need for these has resulted from two major environmental drivers, namely market forces and legislation (Sweatman and Simon, 1996). Eight main approaches have been identified (Van der Horst and Zweers, 1994). These are outlined in Table 2-1. Although these approaches can produce good results they are limited in what they can achieve if applied independently (Van der Horst and Zweers, 1994). Taking any of these approaches it is inevitable that trade-offs will occur. Improving the design of a product can result in neglecting negative aspects of the process. For example, designing in recyclable plastics may mean a large increase in energy costs during the production process. A balanced overall approach is required.

Along with these approaches there are two main types of ECD tools emerging of prime importance. These can be classified into two, somewhat overlapping groups, tools for analysis such as LCA, and improvement tools such as design for recycling (Kortman *et al.*, 1995). Simon *et al.* (1998) found that ECD within companies often takes the framework of analyze, report, prioritize and improve while McAloone and Evans (1997) found five factors that were necessary to carry out ECD, Table 2-2.

Table 2-1 Eight Main ECD Approaches (Van der Horst and Zweers, 1994)

No	Approach	Background	Advantages/Limitations
1	'Closing Materials Cycles'	Key principles are; Extract as few rare materials as possible Continue using raw materials as long as possible through reusing parts and recycling materials	Advantages include; provides useful design criteria Limitations include; Lack of data on recycled material properties and its pollution effects
2	Energy Indicators	Assumes that all environmental decisions can be brought back to one value: energy	Advantages include; A developed life cycle approach with all decisions translated to one value Limitations include; Doesn't account for the range of environmental considerations
3	Hazardous Waste	Focuses on prevention of toxic waste in the product life cycle	Advantages include; Provides designer with a list of toxic materials Limitations include; Too restrictive
4	Life Cycle Analysis	The detailed quantitative assessment of a products environmental burdens	Advantages include; Detailed methodology Limitations include; Time-consuming and expensive
5	Environmental Economic	All the environmental consequences of a product are translated into environmental costs	Advantages include; Working with costs as a unit provides a good guideline Limitations include; Time-consuming
6	Environmental Marketing	The market determines the environmental criteria	Advantages include; Involves the consumer Limitations include; Can lead to dubious claims of products being environmentally friendly
7	Environmental Legislation	Selection of environmental criteria is determined by existing and expected legislation	Advantages include; Prevents the company from too much idealism through providing guidelines Limitations include; Tends to lead to a reactive rather than proactive approach
8	Conceptual	Questions the product concept from an environmental perspective and in the context of sustainable development	Advantages include; Can result in the most far-reaching environmental improvements Limitations include; The most difficult to realize in design practice

Table 2-2 Factors Affecting the Implementation of ECD (McAloone and Evans, 1997)

No.	Factor
1	Initial/Sustained Motivation
2	Communication/Information Flow
3	Whole-Life Thinking
4	Hands-on ECD
5	Positioning in 'the world'

The analysis tools enable designers to identify the environmental impact of a product throughout its life cycle. Furthermore, these tools enable the designers to compare and prioritize different alternatives on their environmental importance (Sweatman and Simon, 1996).

2.2 Traditional Analysis Methods

The basis for most analysis tools is LCA whose methodology is best described by the Society of Environmental Toxicology and Chemistry (SETAC) (Fava *et al.*, 1990). LCA involves considering the environmental impacts of every stage of the product's life, from design through to EOL by identifying all the inputs, such as energy and raw materials, and outputs, such as effluents, emission and waste. Traditionally LCA approaches have involved quantitative analysis structured in four stages - goal definition and scope, inventory analysis, impact analysis and improvement analysis. The inventory analysis comprises of the materials and energy flow analysis of the system within defined boundaries. The impact analysis involves three main stages (Karlsson, 1997):

- Classification, where materials and energy inputs and outputs are classified into impact categories
- Characterization, where the contributions to each impact category are assessed by quantitative or qualitative methods
- Valuation, where the impact of each category is addressed and related to one another and the total impact assessed

Once an LCA study had been carried out Environmental Impact Assessment (EIA) may be utilized to assess the true cost of the product to the environment. The EIA makes use of the results from the inventory stage of the LCA categorizing the raw materials used; energy consumed and discharges into actual effects on the environment. These may include ozone-depleting emissions, acidification and resource depletion. Finally, the data generated by an EIA study may be integrated into the LCA to produce an overall eco-profile (Holloway *et al.*, 1994). The improvement analysis will normally form parts of the ECD process. Common applications of LCA include; to support marketing claims, set criteria for eco-labels, aid product design & redesign, and provide data for policy-making (Poole and Simon, 1996). Some of the more familiar LCA tools are reviewed in Sweatman and Simon (1996) and Vezzoli (1999).

2.2.1 Limitations of Traditional Methods

Disadvantages and limitations of this type of approach include high completion costs, the time required, it is labor intensive, unavailability of the required assessment data, and its failure to address other design considerations such as functionality, reliability and safety requirements (Chen, 1995 and McAloone, 1998). Heijungs (1992) identified one person-year as a reasonable time for a complex study where data is difficult to obtain. The difficulties in defining system boundaries and the lack of a complete list of environmental problems and data means that an absolute measure from an LCA study is not possible. A 'full' LCA involves carrying out a sensitivity analysis to determine whether the choices made with respect to these problems affect the conclusions (Heijungs, 1992). Traditional LCA also fails to take into account MLC considerations and the views of a range of stakeholders in a product's life cycle. The companies interviewed, during the course of this research, felt that traditional LCA was not suited to their needs, as it was too complex and time-consuming to implement.

2.3 Alternative Approaches

A number of alternative, abridged or streamlined approaches have been suggested. There are two main perspectives on how to accomplish the objective of streamlining (Curran, 1996a)

1. Modify the method used for the LCA study
2. Make the process of LCA easier through the establishment of publicly accessible databases at minimum cost.

Modifications to LCA range from methods to "shrink" the boundaries and minimize the amount of data to be collected, to methods to combine qualitative and quantitative data (Curran, 1996a). Analysis of a single issue or life cycle stage can not be considered an abridged or 'full' LCA, Figure 2-1.

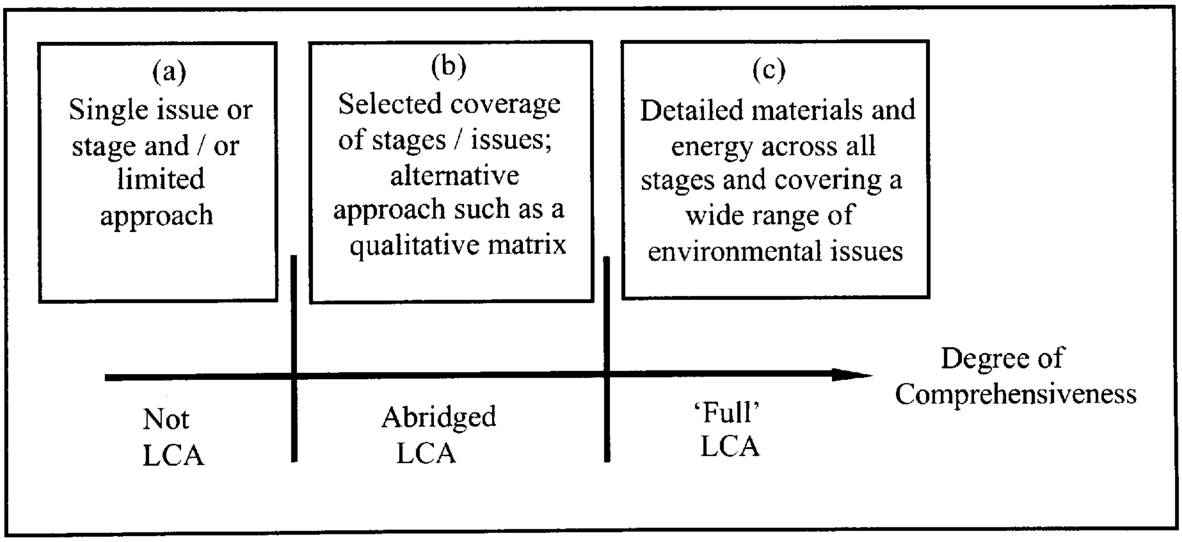

Figure 2-1 Types of LCA

A comprehensive review of the state-of-the-art in streamlining and streamlined tools is given in Weitz *et al.* (1996), Curran (1996b) and Graedel (1998a).

The matrix approach introduced in the previous chapter is one of the most common abridged approaches. Matrices have been previously used as a decision making tool in design. Pugh

(1991) demonstrated the use of matrices in concept screening and scoring. The abridged matrix approach involves selecting and assigning priority weighting to a list of environmental considerations. Sometimes this weighting is done intuitively. Some of the issues may be set by statutory or voluntary regulation. In other cases the decisions about the weighting may be made by the product development team in the light of their own knowledge of the market, the local circumstances, and their own evaluation of the importance of each (Burall, 1996). The matrix should be able to include quantitative data such as energy consumed over the products' life cycle along with qualitative data such as ergonomics. This qualitative data depends on the experience and knowledge of the user. It will involve developing 'rules of thumb' based on practical experience (Heijungs, 1992).

2.3.1 Accuracy of Alternative Approaches

Hunt *et al.* (1998) tested the accuracy of 10 streamlined methods and found that many gave incorrect conclusions at least half of the time in comparison to a 'full' LCA. Their main findings can be summarized as follows:

- A full life cycle approach was necessary to reach valid conclusions.
- The success of streamlined methods was generally not predictable for different product categories.
- The single method with the most promise was the use of qualitative or less accurate data.

These conclusions are similar to the views of Curran (1996a) who claimed that abridged LCA using predominantly qualitative data would typically identify 80% of the useful ECD actions that could be taken. Some of the abridged or streamlined tools commonly used in the design process are discussed in the following sections.

2.3.2 The Environmentally Responsible Product Matrix Approach

Graedel and Allenby (1995) produced one of the better known matrix approaches which has been adopted by AT&T. Their environmentally responsible product (ERP) matrix is constructed of 25 elements each representing a particular environmental concern at a particular life cycle stage, Figure 2-2. The numbers are the designation of the matrix elements. For example, element 4,2 represents the energy consumed during the product use stage.

	Environmental Concern				
Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues
Resource Extraction	1,1	1,2	1,3	1,4	1,5
Product Manufacture	2,1	2,2	2,3	2,4	2,5
Product Packaging and Transport	3,1	3,2	3,3	3,4	3,5
Product Use	4,1	4,2	4,3	4,4	4,5
Refurbishment, Recycling, Disposal	5,1	5,2	5,3	5,4	5,5

Figure 2-2 Environmentally Responsible Product Matrix (Graedel and Allenby, 1995)

A qualitative score, from 0 (highest impact) to 4 (lowest impact), is assigned to each of the 25 elements with a maximum product rating of 100. They recommend that the assessor should be guided in the task by experience, a design and manufacturing survey, appropriate checklists, and other information. The results are profiled using a target plot to pinpoint areas for improvement. Similar matrices have been developed for process, facility and service industry evaluation (Graedel and Allenby, 1995, Graedel, 1998b). Several groups, including Hook (1995), Poole and Simon (1996) and Eagan and Weinberg (1997), have adapted the ERP approach to meet their own specific needs.

2.3.2.1 Weighted ERP Matrices

Graedel (1996) presented a methodology for using weighted ERP matrices to prioritize and emphasize the most important life stages and environmental concerns. The weighting process is a basic mathematical exercise involving doubling the importance of key life stages and/or environmental concerns. These stages and concerns are determined through gaining consensus from the group carrying out the analysis.

2.3.2.2 The Grand Objectives

Graedel (1997b) proposed a framework for relating recommendations for action to environmental concerns. The framework consists of a decision-making process that begins with the 'grand objectives', the common consensus of the vital goals for maintenance and improvement of life on earth which is linked to the ERP matrix approach. Taking issues generally accepted by society as being of universal importance Graedel theorizes on the existence of a small number of grand objectives. These objectives relate to life on earth, its maintenance, and its enjoyment, Table 2-3.

Table 2-3 The 'Grand Objectives' (Graedel, 1997b)

The Omega One Objective	Maintaining the existence of the human species
The Omega Two Objective	Maintaining the capacity for sustainable development
The Omega Three Objective	Maintaining the diversity of life
The Omega Four Objective	Maintaining the aesthetic richness of the planet

The objectives lead to the identification of crucial environmental concerns: global climate change, human organism damage, water availability and quality, depletion of fossil fuel resources, loss of bio-diversity and stratospheric ozone depletion. These concerns lead to determining societal activities that need to be examined. The framework is proposed as a benchmark against which decisions about the use and goals of LCA can be made.

Environmental decisions can be made relating to these objectives even without agreement of their importance. The four-step sequence that links the grand objectives to specific ECD recommendations requires three distinct groups of players, Table 2-3, (Graedel, 1997b).

Table 2-4 Groups of Players for the 'Grand Objectives' (Graedel, 1997b)

Group One	The industrialized society which implicitly or explicitly establishes the objectives
Group Two	The environmental science community which identifies environmental concerns and technological and societal activities connected to them
Group Three	The DfE community which modifies technological activities to minimise their impacts on the crucial environmental concerns

Graedel proposes that the goals of sustainability require the constructive interaction of these groups. Craig (1998) argues that although Graedel's 'grand objectives' system is very useful it is important to recognize that values are inextricably involved at the 'environmental concerns' level. He suggests a way to enhance Graedel's system through translating general values into practical policy direction (Craig, 1998).

2.3.2.3 Reverse Life Cycle Assessment

Graedel (1997a) introduced a new methodology termed reverse life cycle assessment (RLCA) based on the ERP matrix approach. A life cycle flow diagram is used to highlight the main resource flows for a product from manufacture through to disposal. Graedel claims that an ideal green product is one that satisfies the customer need with the absolute minimum environmental impact (Graedel, 1997a). RLCA is very similar in nature to the 'Conceptual Approach' identified by Van der Horst and Zweers (1994). The analysis involves questioning the need for the product, its features and functions.

2.3.2.4 Benefits and Weaknesses of the ERP Approaches

These ERP approaches overcome many of the problems of traditional LCA but they clearly fail to take into account the views of a range of stakeholders. The grand objectives begin to examine stakeholders through linking the ERP framework to issues generally accepted as universally important by society. The grand objectives do not involve establishing the issues of importance to each individual stakeholder grouping over the SLC or MLC of a product.

2.3.3 Other Matrix Approaches

Several other matrix approaches have been developed. Graedel (1998a) reviews a number of these including ones developed by Motorola, Monsanto and Dow Chemical. The basic evaluation matrix used for deciding the criteria for the European Union (EU) Eco-Label scheme is reviewed in Burall (1996). This matrix is used in conjunction with a traditional LCA approach; therefore the process is complex and time-consuming, although subjective qualitative measures can also be included. All the matrix approaches to-date fail to take into consideration the views of a range of key stakeholders for SLC and MLC products. Five of these matrix approaches are reviewed here to illustrate their structure and inherent weaknesses. These are:

- The MET Matrix
- Life Cycle Screening Matrices
- Conceptual Requirements Matrices
- DfE Strategy Matrix
- DfE Benchmarking Matrix

2.3.3.1 The MET Matrix

The MET (Materials, Energy, Toxicity) matrix is a paper-based qualitative tool developed by Brezet and van Hemel (1997), describing a simplified five stage product life cycle and three environmental impacts, Figure 2-3. The columns are intended for notes on environmental problems concerning the materials, energy and toxic impacts at each of the five life cycle stages. The matrix does not include all the key environmental considerations, MLC options or the views of a range of stakeholders.

MET Matrix	Materials Cycle Input / Output	Energy Use Input / Output	Toxic Emissions Output
Production of Materials & Components			
In-house Production			
Distribution			
Utilization			
EOL System			

Figure 2-3 MET Matrix (Brezet and van Hemel, 1997)

2.3.3.2 Life Cycle Screening Matrices

Life cycle screening matrices which consider stakeholder preferences (Figure 2-4a), stakeholder liability (Figure 2-4b) and environmental burden (Figure 2-4c) have been suggested (Karlsson, 1997). These screening matrices are used to examine the environmental efforts of all life cycle stakeholders. This technique does not involve consulting each key stakeholder group although specific requests on issues such as environmental labeling and recycling systems are taken into consideration. MLC considerations are once again ignored in the assessment.

	Stakeholder Preferences				
Life Cycle Stakeholders & Activities	Policies	Objectives	Targets	Purchase Manuals	Other

(a) Stakeholder Preferences Screening Matrix

	Stakeholder Liability				
Life Cycle Stakeholders & Activities	Existing Legislation	Existing Standards	Existing Instruments of Control	Future Liability	Other Liability Issues

(b) Stakeholder Liability Screening Matrix

	Environmental Burdens				
Life Cycle Stakeholders & Activities	Used Amount of Material	Energy Consumption	Transports	Emissions to Air, Water, and Soil	Generated Waste

(c) Environmental Burdens Screening Matrix

Figure 2-4 Life Cycle Screening Matrices (Karlsson, 1997)

2.3.3.3 Conceptual Requirements Matrices

Conceptual requirement matrices for studying the interactions between life cycle requirements have been developed by Keoleian and Menerey (1993). The matrix for each type of requirement contains columns that represent life cycle stages. It includes a legal, cultural, cost, performance and environment level and was developed as a requirements model for industrial ecology. The multi-layer approach is useful but the environment level (Figure 2-5) is limited as it concentrates on inputs and outputs and does not consider the role of stakeholders or products with secondary lives.

	Life Cycle Stages: Raw Materials Acquisition to Treatment & Disposal						
Product 1. Inputs 2. Outputs							
Process ➢ Inputs ➢ Outputs							
Distribution ➢ Inputs ➢ Outputs							
Management ➢ Inputs ➢ Outputs							

Figure 2-5 Environmental Layer of Requirements Matrices (Keoleian and Menerey, 1993)

2.3.3.4 DfE Strategy Matrix

The matrix developed by Holloway (1997) enables the designer to choose an appropriate DfE strategy for a product, Figure 2-6. The main life stages are examined in terms of product life span, energy and resource consumption, material requirements, and configuration and disposal route, with a DfE strategy being highlighted for the product. This approach helps the designer to focus on issues such as material compatibility and selection, but due to a lack of information it is difficult to analyze the product in terms of life span, disposal and MLC options. Thus, the most suitable strategy may not always be selected. Once again the system does not deal with the views of a range of stakeholders.

Strategy Matrix	Energy	Resources	Configuration	Materials	Disposal
Materials & Resources					
Processing					
Distribution					
Use					
Retirement & Disposal					

Figure 2-6 Simplified DfE Strategy Matrix (Holloway, 1997)

2.3.3.5 DfE Benchmarking Matrix

The DfE benchmarking matrix developed by Raychem Corporation incorporates customer and stakeholder concerns about environmental, health and safety (EHS) issues throughout the product life cycle, Figure 2-7. A CFT guides the product through the analysis (Johnson and Gay, 1995). The approach is qualitative and applicable to the broad range of telecom products developed by the company. The tool is used to prioritize environmental concerns and benchmark products but it is limited as it focuses on acquiring information and views from a limited group of stakeholders, i.e., customers and EHS professionals within Raychem Corporation. The approach also fails to examine MLC options.

DfE Matrix	Natural Resource Utilization		Environmental Protection		Worker Protection
Life Cycle Changes	Energy	Materials	Solid Waste	Emissions and Discharges	Health, Safety and Ergonomics
Raw Materials /Components					
Product Manufacturing					
Packaging /Distribution					
Installation/Use					
End-of-Life					

Figure 2-7 DfE Matrix (Johnson and Gay, 1995)

2.3.3.6 Benefits and Weaknesses of Matrix Approaches

All of these matrix approaches have been used to a certain degree of success in analyzing products with single life cycles but their results are limited through a failure to account for the views of a range of key stakeholders and/or MLC issues. The reason why the tools have these in-built limitations may be due in part to the complexity of including them in the analysis. Also, through including stakeholder views and opinions the time taken to carry out the analysis may be substantially increased.

2.3.4 Other Abridged Approaches

Several other abridged approaches have been developed including:

- Environmental Product Development Strategy Wheel
- The Green Design Advisor
- Eco-Compass

These three approaches are reviewed here. Simon *et al.* (1998) reviews a number of other alternative approaches.

2.3.4.1 Environmental Product Development Strategy Wheel

The 'Environmental Product Development Strategy (EPD) Wheel' contains eight 'spokes'; which represent the various strategies, which can be followed to reduce the environmental impact of the product (Bottcher *et al.*, 1998). The spokes are: optimize functionality, improve the qualitative aspects of materials, reduce the quantity of materials, optimize production technology, optimize distribution, reduce burden during use, extend life cycle and optimize 'End-Of-Life' cycle.

2.3.4.2 Green Design Advisor

The National Center for Manufacturing Sciences and its member companies developed a 'Green Design Advisor Computer Aided Engineering' tool to support designers and manufacturing engineers in assessing and minimizing the environmental impacts of their products and processes (Wixom, 1994). The tool analyses a design against set environmental criteria.

2.3.4.3 Eco-Compass

The Eco-Compass technique is a comparative tool used to evaluate one existing product with another, or to compare a current product with new development options (Yan *et al.*, 1999). It has six dimensions, intended to encompass all significant environmental issues: mass intensity, energy intensity, health and environmental potential risk, revalorization, resource conservation and service extension. Using the technique one of the products is always chosen as the base case and scores a 2 in each dimension. The other product is given a score relative to the base case on a scale of 0-5 in each dimension.

2.3.4.4 Benefits and Weaknesses of Other Abridged Approaches

These tools are again useful in that they overcome some of the problems associated with quantitative LCA but like the matrix approaches they fail to account for the views of a range of key stakeholders. Unlike the matrix approaches the EPD strategy wheel includes MLC considerations. Two 'spokes'; extend life cycle and optimize 'end-of-life' cycle, force the assessor to focus on MLC options.

2.3.5 Modifications to Existing Quality Tools

Existing design and quality tools have been modified to incorporate environmental concerns. Environmental Objectives Deployment (EOD) is a variant of the house of quality in Quality Functional Deployment (QFD). In EOD the relationship between the identified environmental problems and the products technical descriptors are examined (Karlsson, 1997). Like QFD, EOD focuses on customer requirements. An 'Environmental Impact and Factors Analysis' approach which examines the potential hazards to the environment posed by individual or clusters of components in a given design has been developed by Stanford University (Environmental Impact and Factors Analysis, 1998). It is analogous to the Failure Modes and Effects Analysis (FMEA) technique but has been restructured to address environmental considerations instead of component failure. Pareto analysis is used to reveal what parts may be found to be contributing to the majority of the product impacts. The approach employs a systematic method of evaluating the current design and potential redesign options using a non-dimensional scoring system.

2.3.5.1 Benefits and Weaknesses of the Modified Quality Tools

These tools are quick and relatively inexpensive to use and possess the added benefit that designers should be already familiar with their structure. On a negative side, they again fail to take into account the views of a range of stakeholders over a products life cycle. QFD and EOD tools are designed to include the views of customers and thus in theory could also include the views of a range of stakeholders. This has not been the case in practice.

2.3.6 Limitations of Current Alternative Approaches

In summary, although all of these alternative approaches overcome many of the problems of traditional LCA they still fail to take stakeholders into account. Stakeholder views and opinions do not get through in a format that can be used in the abridged assessment. Therefore all the key environmental considerations over both SLC and MLC products are not being addressed at the design stage.

2.4 Improvement Tools

Analysis tools are only useful to a certain degree in the design process. Once the priority environmental issues have been identified and analyzed, a methodology is required to improve the situation. Improvement tools facilitate and assist designers to generate improvement options for products in the different stages of the life cycle. The diversity of environmental considerations has resulted in the development of a wide range of improvement tools. These tools address issues such as remanufacture, energy efficiency, disassembly, and recycling, and compliance with regulations and standards. These improvement tools and methodologies can be broadly grouped under checklists, handbooks and concept demonstrators and are reviewed in Sweatman and Simon (1996). Brezet and van Hemel (1997) developed a comprehensive handbook that .includes a seven-step strategy for successful eco-design. Concept demonstrators present a tangible vision of the possible product of the future and offer a number of benefits to the design process. They require the input of all of the participants in the design process from marketing to management. One example is the 'Green Television' developed by Philips. This is designed to take advantage of the latest trends in environmental design to assist in the design process. The improvement tools can also be grouped under those with a broad base or those with a specific application. Broad-based tools offer improvement suggestions for the main environmental considerations. One example is the eco-design tool for product development developed at Manchester Metropolitan University (Poyner 1997). Specific tools tend to cover only one issue, for example, the material selection tool by developed by Chen (1995). Some of the more common available tools and methodologies for each of these groupings are reviewed in Sweatman and Simon (1996), Poyner (1997), Holloway (1997), Simon *et al.* (1998) and Vezzoli (1999).

2.4.1 EOL Strategies and Product Definition

Ishii and Lee (1996) developed a Reverse Fishbone Disassembly Diagram to aid design for recycling and reuse. The recycleability map evolved from this, focusing on two key factors, disassembly complexity and recovery efficiency. The map assists in generating improvement ideas and identifying opportunities for recycling technology development. These tools are useful when redesigning an existing product but fail when designing new products as the EOL paths are not usually known (Rose, Ishii and Masui, 1998). Designers must clearly define the EOL strategy before considering recycling or re-manufacturing. Case studies on Office Automation (OA) and Information Technology Equipment indicate a relationship between product characteristics and EOL strategies. Depending on a product's characteristics, an optimal EOL strategy may be different. Designers typically have strong influence over product characteristics such as wear-out life, number of modules, functional complexity and technology cycle. These characteristics have been categorized into four generic factors: external, material, disassembly and inverse supply chain (Rose, Ishii and Masui, 1998). A web based EOL Design Advisor tool is currently being developed with its main goals being to increase designer environmental awareness, predict EOL strategies from product characteristics, and assist in decision making (Rose, Beiter and Ishii, 1999)

2.4.2 Traditional Improvement Tools

Improvement tools such as analogy, trigger word, brainstorming and empathy have been traditionally used by designers to come up with creative solutions. Many of these creativity tools are reviewed in Plsek (1998) in the context of improving the quality of a product. Very little effort to date has been made on applying these tools in the pursuit of environmental improvements. In their handbook, Brezet and van Hemel (1997) begin to relate some of these traditional tools to eco-design. The E-Co Challenge[2] team has recently begun to apply creative techniques in environmental projects but no significant results have been published to date. Jones *et al.* (1999) proposes a design tool, the 'Product Ideas Tree' for mapping creativity in eco-design. The generic design tool combines a standard design process form; mind maps, based on Buzan and Buzan (1995), and visually based eco-design tools such as the 'EPD Strategy Wheel'. The tool will record all the ideas generated whilst simultaneously mapping them onto the stages of the design process. The tool needs to be researched and tested.

2.4.3 Limitations of Current Improvement Tools

The improvement tools currently available are useful to an extent but more research is required on the effectiveness of established creativity tools in the pursuit of environmental improvement. Techniques, such as 'escape provocation' or 'PO', developed by De Bono (1981), which have been successfully applied in management and quality situations, may be able to assist the designer in significantly improving the environmental performance of a product. The effectiveness of these techniques needs to be investigated.

2.5 Identification of Key Product Requirements

There has been very little research to date on identification and weighting of key product requirements through consulting a range of stakeholder groupings. Rothwell and Gardiner (1984) classified requirements by customers and found reliability to be the top issue. The Kanomodel, outlined in Karlsson (1997), defines the needs and expectations of the customer in terms of product quality. The model divides customer needs into three categories: basic, expressed and unconscious. Karlsson (1997) claims that the environmental needs of customers should be fitted into this model. Basic needs include health and safety; expressed needs may include ease of disassembly and recycling; unconscious needs may concern issues unknown to

[2] E-Co Challenge is a Department of Trade and Industry Sector Challenge Research Initiative.

the customer. As environmental issues are complex, customers will not be able to identify a set of rational product criteria for the products full life cycle (Karlsson, 1997). Customers can still provide useful information for the usage stage (O' Connor and Blythe, 1997). The Open University (OU) carried out a study of the environmental considerations being taken into account by 16 companies in green design projects in 1994 (Burall, 1996). As can be seen in Table 2-5, there is quite a range of criteria being examined with no single issue dominating.

Table 2-5 Key Green Criteria as Specified by 16 Companies (Burall, 1996)

Criteria	% Companies
Materials used in product	19
Pollution/waste from manufacturer	16
Energy consumed in use	13
Environmental impacts of use	11
Potential for recycling	11
Pollution/waste in disposal	11
Energy consumed during manufacture	8
Design for re-use	5
Other	5

Only one of the companies in the survey thought that environmental performance was the single most important factor in its competitive advantage; most attributed their success to overall quality, specification and value for money. Interestingly, the key finding from the study was that an environmental perspective spurs companies into an approach to innovation and design that leads to efficient, high performance, profitable products.

The key environmental requirements for different stakeholder groupings over the life cycle of a product have not been established for electromechanical products. These requirements could be weighted and used in an abridged matrix approach to provide a profile for products with either a SLC or MLC. This 'body of knowledge' would reflect the views and opinions of a range of stakeholder groupings and not just the design team or environmental assessor carrying out the exercise. Using this information the design team or environmental assessor would be able to weight dissimilar environmental effects against each other to clarify which product concept is less harmful. The 'body of knowledge' would ensure that multi-criteria value judgements are based on a range of stakeholders, and not an individual, or a small team of people.

2.6 Ranking and Weighting

The International Organization for Standardization (ISO) provides the following definition for weighting (ISO, 1997):

"Weighting aims to rank, weight or possibly aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results."

Ranking and weighting distinguishes between critical and desirable requirements. Keoleian and Menerey (1993) provide one classification system, Table 2-6. Once 'must' requirements are specified, 'want' and 'ancillary' (or wish) requirements can be assigned priorities. Judgments based on the values of the design team are used to arrive at priorities, with trade-offs required between different requirements. Complex environmental decisions require the views of other major stakeholders to be represented in this prioritization process. There is currently no mechanism for this.

Table 2-6 Ranking Classification System (Keoleian and Menerey, 1993)

Must	Conditions that designs have to meet such as Government requirements.
Want	Desirable but not mandatory.
Ancillary	A wish list which are only expressed in the design when they do not compromise more critical functions.

Lundie and Huppes (1999) identified three aspects that characterize multi-criteria decision-making:

- Several criteria to be judged on
- Decision making variables
- A process of comparing alternatives

Lundie and Huppes (1999) suggest that some of the disadvantages of LCA can be overcome by applying decision-making methods.

2.7 Role of Stakeholders

Smith and Haines (1995) recognized that consulting stakeholders on environmental performance was an important tool in assessing a company's environmental performance. In developing a guide to LCA, SustainAbility (1999) conducted a sample survey of industrial practitioners, standard setting organizations, eco-labeling boards, industry associations, research institutes, consultants, non-governmental organizations, students, the environmental media and financial institutions. These stakeholders indicated that LCA, in its various forms, is a necessary, integral part of the environmental management tool-kit and that further development was required. They also felt that the involvement of external stakeholders in defining study boundaries and stimulating 'out-of-box' thinking was becoming increasingly important. McAloone (1998) found that in ECD designers had to consider may different life cycle stages and many different stakeholders all at once. The designers found that existing tools and techniques were not suitable. McAloone (1999) identifies the importance of considering all of the stakeholders in the very early product development stages. Through considering all of the stakeholders McAloone (1999) suggests that we can begin to anticipate the life cycle of the products being designed, and ensure the development of innovative solutions. Vezzoli (1999) states that new ECD support tools will have to be able to adapt and interface effectively with various stakeholders in the product development process.

2.8 Societal Values

Hofstetter (1996) cited in Lundie and Huppes (1999), identified up to thirty different methods for identifying the most environmentally friendly product alternative. All methods were based – implicitly or explicitly on different societal values (Lundie and Huppes, 1999). Focusing on transparency and reproducibility Lundie and Huppes (1999) propose an approach that uses consensus-oriented ranges of societal values for specifying the ranking of the overall environmental attractiveness of alternatives. These ranges can indicate both the uncertainty of decision-makers and the shifting of societal values. The approach combines environmental data and uncertain societal values to form a statement on alternatives regarding their environmental damage. The step by step procedure is illustrated in Lundie and Huppes (1999), using the case study of television housing concepts, and a survey based on the Delphi Method[3]. Lundie (1998) cited in Lundie and Huppes (1999), selected the simple additive weighting-method (SAW-method) as the most appropriate technique for combining impact category scores with preferences of decision-makers. For each alternative, the SAW-method calculates an environmental index by multiplying normalized environmental data with the societal preferences and finally summing up these terms. The smallest index calculated indicates the most environmentally friendly product alternative that causes the least environmental damage according to the preferences of the decision-makers. Lundie and Huppes (1999) suggest that societal values are dynamic and depend on the decision-makers asked, the time of the survey, and the knowledge of the environmental problem area considered. They identify four ways of distinguishing between different bases of information for societal preferences:

- The preferences are fully unknown concerning the importance of impact categories. In this case, a decision has to be made on the pure environmental profile of alternatives.
- Bounded set of preferences ("Ratio 10"): "Ratio 10" means that the ratio between the most and least important environmental issue is smaller that 10.
- Application of a range of societal preferences. A range of preferences expresses the uncertainty. These can be given by a survey.

[3] The Delphi Method is a set of procedures for eliciting and refining the opinions of a group of people (Dalkey, 1969). It was developed at the Rand Corporation.

- Fixed societal preferences can be applied if there is detailed knowledge of and agreement on societal preferences. There are several ways these can arrive, including from government aims, sustainability criteria and surveys. Each way would probably lead to different fixed societal preferences.

The approach adopted by Lundie and Huppes (1999) of applying "Ratio 10" and a range of societal preferences is very useful. It makes it possible to deduce a highly accepted ranking of alternatives based on intervals of societal preferences. The key weakness is that the societal weightings evolved from 10 decision-makers and not from of a range of stakeholder groupings.

Graedel (1997b) grouped the relative significance of the impact of each environmental concern on a local, regional and global scale before ranking them using criteria set by the World Commission on Environment and Development. SETAC (1997), cited in William Owens (1998), noted that environmental mechanisms operate on different spatial scales (global, regional, and global) and temporal scales (decades, years, months, and days). Finnveden (1997) found that LCA weighting factors and the choice of evaluation methodology are influenced by fundamental ethical, moral and ideological choice. Finnveden concluded that since there is no societal consensus on these values there is no reason to expect consensus on evaluation although discussing these values explicitly should be a prerequisite for increased agreement. In this paper Finnveden also examines the role of expert panels in making decisions. He proposes the formation of an 'expert panel' consisting of 'expert' representatives from different stakeholder groupings but then suggests the panel may be too authoritative for some people. Hofstetter (1996), cited in Finnveden (1997), suggested the construction of several lifestyle-dependent weights by use of a cultural perspective. Volkwein *et al.* (1996) presented a formalized method of prioritization by expert panels for quantitative LCA. This approach is useful but the expert panel do not consist of representatives from different stakeholder groupings and are primarily involved in valuation of the results and not in establishing the initial environmental concerns.

2.9 Views from Industry and Academia

It is clear from the literature reviewed that new ECD tools will have to be able to adapt and interface effectively with various stakeholders in the product development process and throughout the life cycle of a product. A multi-national computer company and a prominent research institute were contacted to discuss ECD approaches and the role of stakeholders. The former interview was used to help identify the research need and formulate the project objectives. The latter one was carried out mid-way through the project to re-confirm the need to focus on the role of stakeholders in ECD.

2.9.1 An Industrial View

In a telephone interview and subsequent follow-on discussion by electronic mail (email) Mr. D Tsuda[4], the Environmental Engineering Strategies manager at Apple Computers, identified that an ECD methodology should have a number of key characteristics to make it practical for application in industry, Table 2-7.

Table 2-7 An Industrial Viewpoint on the Key Characteristics for an ECD Methodology

No.	Characteristic
1	Consider environmental concerns alongside traditional requirements.
2	Examine SLC and MLC options.
3	Consider cost. If cost is introduced people tend to get very creative.
4	Consider time. The tool must be quickly accessible, integrated with what the design engineers already are familiar with, and should be easy and intuitive in its use. Product development decisions need to be made quickly. Computer companies can not afford to wait a few months or longer for the results of an environmental analysis. The time to market for a new computer is less than a year. Time from product concept to sale of a peripheral device, such as a keyboard, is substantially less.
5	Be able to identify up to 80% of the useful ECD actions that can be taken.
6	Actively seek out and consider the views of external stakeholders such as recycling companies. They know their business better than anyone else does and they need to operate at a profit.
7	Include a link to an improvement option

[4] Contact details for Mr. Tsuda are given in Appendix A.

Mr. Tsuda felt that systems studied to date failed to satisfy these requirements.

2.9.2 An Academic View

The key extracts from an interview and follow-on discussion by email with Dr. G. Keoleian[5], the manager of the National Pollution Prevention Center at the University of Michigan, are as follows:

"The concept of involving key stakeholders in product design and management is becoming more and more recognized. Currently, there are many cases where stakeholder groups have been formed to support corporate environmental management. Companies are recognizing the need for external stakeholder input. With regard to the product development process, external stakeholder involvement (total life cycle) is rare. Of course, suppliers and customers are stakeholder groups that have been traditionally involved. Life cycle partnerships have also been formed to address key problem areas such as EOL management of automobiles. The United States 'CAR Vehicle Recycling Development Partnership' is an example. The program, however, is not directly linked to the product development process. It is more of a Research and Development or strategic activity. I hypothesize that the more stakeholder representation in the product development process the more likely the product will be successful when launched. The representation does not necessarily mean that external stakeholders are at the table. As long as there is a mechanism for incorporating their requirements/strategies in the process through internal stakeholders or cross-functional team members then upstream and downstream factors should be captured."

Dr. Keoleian highlights the importance of having stakeholder representation in the product development process.

[5] Contact details for Dr. Keoleian are given in Appendix A.

2.9.3 Summary of Views from Industry and Academia

An ECD approach is required which can be applied quickly, yet effectively, in the analysis and improvement of designs, considering environmental issues alongside traditional requirements. Stakeholders need to be represented in this approach so as to ensure successful ECD.

2.10 Summary

This literature review has provided a critique of the research work that has been undertaken in this subject area. Clear limitations in the current knowledge have resulted in a research and industrial need.

2.10.1 Limitations of Current Knowledge

Although all of the approaches and tools discussed are useful for certain situations and certain aspects of the design and product life cycle none of them provide a stakeholder 'body of knowledge' and methodology which can be applied to a generic family of electromechanical products and their packaging. The key limitation is the failure to account for the views of a range of key stakeholders. This information does not reach the assessor in a form that can be applied in abridged ECD for SLC and MLC products. As a result of this failing, a suitable life cycle strategy is not being selected, and all of the key environmental considerations are not being identified and analyzed at the design stage. The effectiveness of creativity tools in the pursuit of environmental improvements has not been established. These tools have been successfully applied in management and quality situations.

2.10.2 Research Need

From the literature review and interviews conducted with industry and academia it can be seen that there is a need to pay particular attention to the role of key stakeholders in ECD. Current abridged approaches have been relatively successful but they have failed to explore or define the role of key groups of stakeholders for SLC and MLC products.

2.10.3 Industrial Need

From the interviews conducted with industry it can be seen that the new methodology must be quick to use, cost-effective and consider environmental concerns alongside traditional requirements. The methodology also needs to examine SLC and MLC options, actively seek out the views of a range of internal and external stakeholders, link to an improvement option and be able to identify up to 80% of the useful ECD actions.

2.11 Conclusions

- There is a clear need for a comprehensive ECD approach for electromechanical products.
- The approach needs to examine both SLC and MLC considerations.
- The approach needs to consider the optimum life cycle strategy at the design stage.
- An abridged approach provides the most viable solution.
- This abridged approach should consist of a 'body of knowledge' and a methodology to apply it.
- The 'body of knowledge' should be developed through consulting the key stakeholders using surveys, case studies and a focus group.
- The methodology could involve the use of worksheets, flow diagrams, matrices, checklists, guidelines, profiles and other creative and improvement techniques. Although a matrix approach is the preferred abridged approach the 'body of knowledge' could also be applied with another approach such as the EPD strategy wheel.
- The approach should be tested and refined in a number of studies on current market products.
- The approach should be implemented as early as possible in the design process as part of a GCE program using a multi-functional LCT. If resources and time allows a full

quantitative LCA could be started in parallel with the abridged study used as an early indicator.

3 Research Methodology

This chapter outlines the research methodology and provides some background on the main research techniques.

The aims of the chapter are to:

- outline and justify the main research techniques to be used in data collection
- present an overview of the research approach

The study began with a review of all available literature on ECD. The subjects of 'design', 'environment', 'abridged approaches', 'product stakeholder' and 'product life cycle' were explored, with an emphasis being placed on abridged approaches and the role of key stakeholder groups. This secondary research provided an excellent insight into the various aspects of the research topic. From this the primary information sources were identified and explored in greater detail to build up a database of the current 'state of the art'. This stage was continued through the life of the project to ensure that the research stayed relevant and original. The research need was then identified (Section 2.10.2). The aim was to collect information, views and opinions, from herein known as a 'body of knowledge', from a wide range of stakeholders, including designers, manufacturers, users and EOL asset managers. This 'body of knowledge' included a list of environmental categories to be used in an abridged ECD methodology for SLC and MLC products. It ensured that multi-criteria value judgements are not based on the individual designer, but on a range of stakeholders. The 'body of knowledge' was generalized for a range of electromechanical products.

3.1 Research Methods

ECD is a relatively new and emerging topic, and as such little has been documented about the most appropriate strategy or methods to carry out research. It is important to identify and understand the ways in which the research need could be explored with sociological theory offering many different methods and approaches. Robson (1993) classifies the research purpose into exploratory, descriptive, or explanatory, Table 3-1. A particular study may be concerned with more than one purpose.

Table 3-1 Classification of the Research Purpose (Adapted from Robson, 1993)

Exploratory research aims to establish what is happening, seek new insights, ask questions and assess phenomena in a new light. A qualitative approach is often adopted.
Descriptive research aims to portray an accurate profile of persons, events or situations and requires substantial knowledge of that situation. The research can be qualitative and/or quantitative.
Explanatory research aims to explain a situation or problem, usually in the form of casual relationships. The research can be qualitative and/or quantitative.

A descriptive or explanatory research purpose were decided not to be appropriate as the role of stakeholders in ECD is a new and emerging topic and is not an established situation. The approach adopted was predominantly exploratory, allowing freedom to evolve as the research developed. This approach was felt to be the most appropriate for gathering a stakeholder 'body of knowledge'. Two recent studies in ECD successfully applied exploratory approaches (Dewberry, 1996 and McAloone, 1998).

3.1.1 Qualitative and Quantitative Research

A multi-method research approach was chosen which involved the use of numerous qualitative and quantitative methods. Qualitative and quantitative methods view a subject from different perspectives and hence, when used together, the information gathered can offer a more holistic view of the subject under investigation with the techniques often complimenting each other. Qualitative methods allow researchers 'to get close to the data' and to derive their concepts from the data that are gathered, being considered 'soft, subjective and speculative' (Burgess, 1984). Techniques applied include participant observation and semi-structured interviews. Quantitative methods are considered as 'hard, objective and rigorous' (Burgess, 1984). These methods require facts and figures to satisfy the research need and include techniques such as experiments and surveys. A detailed overview and comparison of qualitative and quantitative approaches is given in Dewberry (1996). The approach was not to scientifically or statistically prove a hypothesis, but to develop a clear understanding in this new area and generate usable data. Starting with the pilot study of PCs the collection and analysis activities were carried out simultaneously, allowing natural development of an understanding of this new subject area for PCs and a range of electromechanical products.

3.2 Chosen Techniques

There are many types of research method that can be used to collect the data necessary to satisfy the research need. The three main research methods, surveys, case studies, and a focus group chosen for this research are outlined below. A number of others techniques including document review, product analysis, participant observation and consultation were fundamental to these. It should be noted that the list of research methods presented is not exhaustive and represents merely those used in this study. Other techniques were considered but were not found to be appropriate. Detailed reviews of common research approaches, techniques and tools have been undertaken recently (McAloone, 1998 and Dewberry, 1996).

Surveys

A survey commonly refers to the collection of standardized information from a specific population usually by means of a questionnaire or interview. Although a survey is well suited to descriptive research they can also be used in exploratory studies (Robson, 1993). All questionnaires and interviews need to be tested and refined in pilot runs.

Questionnaires

Questionnaires are a useful means of gathering usable information such as trends and personal views from members of a large population such as product users. They can contain 'Yes/No' type questions or can be open-ended in nature and can be used for descriptive or exploratory research purposes. When selecting participants it is important to remember that their opinions are an unreliable guide unless they have had considerable experience of the product in question.

Informal Interviews

By virtue of its flexibility and wide range of form, from unstructured, open-ended questioning to structured sessions, the interview is a frequently utilized research technique (Tomlinson and Johnson, 1994). Interviews were felt to be a suitable technique for various stages of this research. The interviews were designed semi-structured, with a frame of reference for respondents' answers, but with a minimum of restraint on the answers and their expression. Semi-structured interviews allow the interviewer to probe any misunderstandings, and can result in "unexpected or unanticipated answers" (Cohen and Manion, 1989). A conversational map seen by the interviewer but not by the interviewee was used. The intention was to get the interviewees talking with little interruption and without leading them.

Case Studies

Case studies concentrate on one situation in its' own environment and do not limit their investigation to standardized, pre-determined lines of enquiry; instead they find out as much information as is available, by as many means as are available. Case studies have several advantages that make them useful for this type of exploratory study. The cases do not have to be representative of a larger sample but can provide examples of "best practice" (Hinnels, 1995) Also, case studies can give the complex details of phenomena that are difficult to convey with quantitative methods alone. They can utilize multiple sources of evidence, both quantitative and qualitative and allow a variety of theoretical arguments to be explored. Documents, product analysis, participant observation and consultation through semi-structured interviews are important sources of research information for case studies.

Focus Groups

Focus groups, sometimes described as forums, are a method of discussing issues around a specific topic, with a specialized group of participants. There are especially effective in exploring new topics and hypotheses thus making them suitable for this research.

3.3 Chosen Research Approach

The research approach involved a number of distinct phases to arrive at the 'body of knowledge' and develop the new ECD methodology, Figure 3-1. The results were analyzed using a number of techniques including computerized methods, matrices, profiling and through grouping key criteria into categories.

Phase 1: Pilot Study

A pilot study was undertaken to verify and compare the questionnaire and informal interview approaches for gathering the 'body of knowledge' from stakeholders. The study focused on users and PCs and provided a methodology for analyzing the results in the main study.

Phase 2: Main Study

The main study involved three main sections: PCs, Electromechanical Products and Packaging. A 'body of knowledge' evolved from these that was then applied to a matrix-based approach resulting in a new ECD methodology.

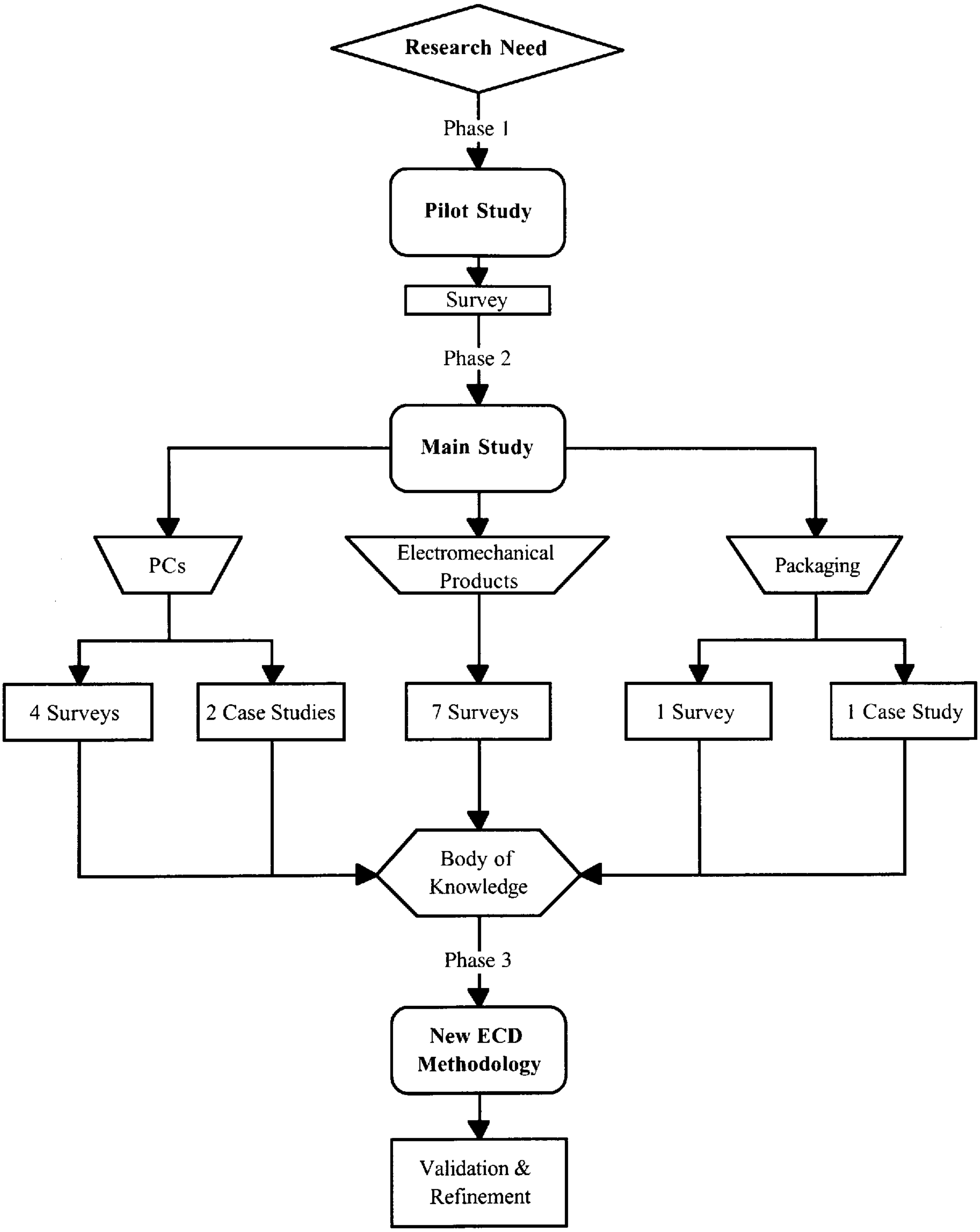

Figure 3-1 Simplified Research Approach

PCs

This section involved four surveys and two industrial case studies. The main aims of the surveys were to identify and group key requirements and environmental considerations for PCs into a list of categories and to provide relative weightings, focusing on the environmental categories. Details of the surveys are given in Table 3-2.

Table 3-2 Surveys of PCs

Survey	Type of Question	Participants	Product Group
A	Open-ended / Closed-end	Range of Stakeholders	PCs
B	Closed-end	Range of Stakeholders	PCs
C	Closed-end	Trainee Product Designers	PCs
D	Closed-end	ECD Experts	Computer Keyboard

The open-ended questions were used to identify and undertake some initial categorization of the relative importance of requirements and environmental considerations. The closed-end surveys involved getting stakeholders to weight the key requirements and considerations identified in the open-ended sessions. The views and opinions of similar stakeholders are compared in 'Survey D'. This will have an impact on the speed of completion of the ECD methodology, and may have an impact on the quality of the data. The industrial case studies involved collection and analysis of information from a range of internal and external stakeholders in the environmental analysis of a computer component and a computer product designed and manufactured by Alps. Details of the case studies are given in Table 3-3.

Table 3-3 Case Studies of PCs

Case Study	Participants	Product Group
1	Range of Internal & External Stakeholders	Computer Component
2		Computer Keyboard

The evidence was gathered using a combination of documents, product analysis, participant observation and informal discussions with a range of stakeholders involved in the component or product life cycle under investigation. Observation was particularly useful in reporting on the manufacturing and usage stage of the product. The multi-method approach provided qualitative and quantitative field data for the 'body of knowledge' and a means of testing and refining the developing methodology. An iterative abridged ECD approach, using input-output flow diagrams, matrices, profiles, checklists and other techniques, was applied.

Electromechanical Products

This section involved six surveys and a focus group[6]. Details of the survey are given in Table 3-4. The main aims of 'Surveys E, F, G and H' were to identify and group key requirements and environmental considerations for a range of electromechanical products into a list of categories and to provide relative weightings, focusing on the environmental categories. 'Survey I' involved getting ECD experts to examine the concept of involving stakeholders in ECD through a focus group. It also provided a means of predicting future requirements.

Table 3-4 Surveys of Electromechanical Products

Survey	Type of Question	Participants	Product Group
E	Open-ended	Range of Stakeholders	Range of Products
F	Closed-end	Range of Stakeholders	Televisions and Microwave Ovens
G	Closed-end	Trainee Product Designers	Range of Products
H	Closed-end	ECD Experts	Three Products
I	Open-ended / Closed-end	ECD Experts (Focus Group)	Four Products.
J	Open-ended / Closed-end	Range of EOL Stakeholders	Range of Products.
K	Open-ended / Closed-end	Range of Stakeholders	Photocopiers & Facsimile Machines

'Surveys J and K' involved identifying EOL and MLC issues for a range of products through questionnaires and informal interviews, containing a combination of closed-ended and open-

[6] For the purpose of this research the focus group has been indexed as 'Survey I'.

ended questions. The views and opinions of similar stakeholders are again compared in 'Surveys H and J' respectively.

Packaging

This section involved one survey and one industrial case study. The main aims of the survey were to gather category weightings for application in a matrix-based approach for packaging. Details of the survey are given in Table 3-5.

Table 3-5 Packaging Survey

Survey	Type of Question	Participants	Product Group
L	Closed-end	Trainee Product Designers	Consumer Packaging

The industrial case study involved testing the effectiveness of one ECD improvement approach in a case study of television packaging along with providing field data for the 'body of knowledge' and methodology. Details of the case study are given in Table 3-6. An iterative abridged improvement approach, using idea generation techniques was applied. The study also involved carrying out an analysis of the packaging, reviewing documents and informal discussions with a range of stakeholders involved in the packaging life cycle under investigation.

Table 3-6 Packaging Case Study

Case Study	Participants	Product Group
3	Range of Internal & External Stakeholders	Television Packaging

Phase 3: New ECD Methodology

This phase of the research entailed the data analysis and methodology development. The 'body of knowledge' from all the studies was collected and analyzed. A methodology was developed to incorporate this 'body of knowledge' into ECD. Documents also provided a valuable source of historical information in developing the methodology providing information on subjects such as EOL reasons and product life spans. The new methodology was then tested, validated and refined in two separate studies of a photocopier and mobile phone.

3.4 Strengths and Weaknesses of Chosen Techniques and Approach

A detailed review of the strengths and weaknesses of the chosen techniques for this type of exploratory study are outlined in McAloone (1998) and Dewberry (1996). The key advantage of the case studies is that they can utilize multiple sources of evidence, both quantitative and qualitative. Care was taken to ensure the researcher did not become too absorbed into the culture of the different company situations and remained impartial about the data collected. The techniques chosen in the initial surveys ensured that the 'body of knowledge' gathered would not be influenced by the views of others. This was vital to ensure the validity of the data. Pilot studies were carried out to ensure the participants would understand the questions. Using trainee product designers offered a number of advantages to the research approach. Although they were not practicing design stakeholders, they had completed an ECD module and applied abridged ECD tools, and were thus able to give valuable opinions on the identification and weighting of the environmental categories. They also ensured unconstrained thinking in the packaging case study. To overcome the difficulty of getting expert participants together the focus group was held during an eco2-irn[7] forum at the University of Glamorgan (UOG). One key benefit of the research approach is that it was chosen to be predominantly qualitative. This allowed opinions and feelings to be taken into consideration in the data analysis, ensuring a comprehensive stakeholder 'body of knowledge' was gathered. The progression from the pilot study through to the main study, using a multi-method approach

[7] eco2-irn - ecologically & economically sound design & manufacture - interdisciplinary research network

allowed for the 'body of knowledge', in particular the environmental categories, to be tested among a wide audience and in a variety of situations. This ongoing data gathering, confirming and testing ensured the validity and generalizability of the approach.

3.5 Summary

The chosen research methods and approach have been outlined. The research was of a predominantly exploratory nature. Techniques applied included surveys, case studies and a focus group. The multi-method approach involved three main phases: pilot study, main study and validation and refinement of the new ECD methodology. The data gathered was predominantly qualitative and is presented through a stakeholder 'body of knowledge'. The final deliverable of this research is a methodology for integration of this stakeholder 'body of knowledge' into ECD.

4 Results and Discussion Of Pilot Study

This chapter presents and discusses the pilot study results. The pilot study was undertaken to verify the survey approach; along with to build an understanding of what constitutes the key requirements and environmental considerations for one product group and one group of stakeholders. The matrix approach that emerged from the findings of the pilot study was then used as a framework for the development of the new ECD methodology.

4.1 Background to Pilot Study

A simplified approach is given in Figure 4-1.

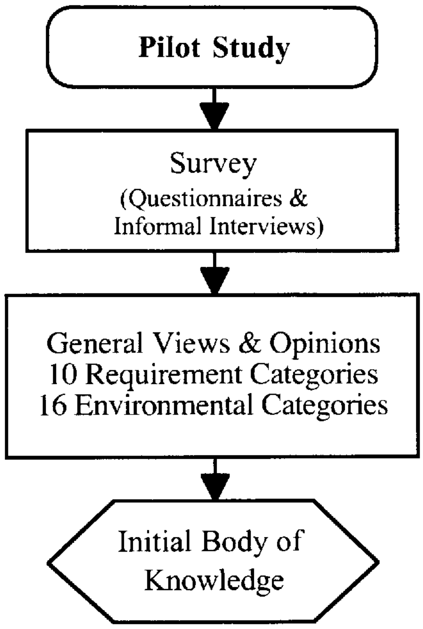

Figure 4-1 Simplified Pilot Study Approach

The main aims of the pilot study were:

- To verify and compare the chosen techniques for gathering the stakeholder 'body of knowledge'.
- To validate the structure and wording of the questionnaire for gathering stakeholders general views and opinions.
- To provide an understanding of what constitutes the key requirements and environmental considerations for one product group and one group of stakeholders.

One group of stakeholders, namely 'users', was chosen for the study. A total of 14 users were selected to participate. PCs were chosen as the product grouping. The study took the form of questionnaires and informal interviews, using the questionnaire as a conversational guide to identify, rank and weight users key requirements and environmental considerations. The study also involved gathering the general views of users on a number of other related issues: take-back, renting and leasing, paying extra for products with perceived environmental benefits, and companies providing environmental information with their products. A summary of the initial results and conclusions drawn from this study are given in O' Connor and Blythe (1997). The chosen methodology was to gather the information from 10 participants through open-ended questions using questionnaires and informal interviews. The results were then presented through a closed-ended questionnaire to 4 different users to rank and weight key requirements and environmental considerations, using Table 4-1 and Table 4-2 respectively.

Table 4-1 Ranking Scale for Pilot Study

0.1	0.5	2.5
Wish	Want	Must

Table 4-2 Weighting Scale for Pilot Study

1	2	3	4	5
Not Important	Low Importance	Medium Importance	High Importance	Very High Importance

4.2 Pilot Study Results

In all, 37 product requirements and 46 environmental considerations were identified during the open-ended sessions. A summary of the 'top 4' requirements and environmental considerations is given in Table 4-3. The most frequently identified product requirement was unit cost, while the most frequently identified environmental consideration was ergonomics. In the closed-ended sessions the two most highly ranked and weighted requirements were reliability and warranty. The two most highly ranked and weighted environmental considerations were safety and reliability. The selection of reliability as one of the top requirements is consistent with the work of Rothwell and Gardiner (1984). Although environmental friendliness was identified as a key product requirement it did not emerge as important in either session. Safety is the only environmental consideration that shows up in both columns in the 'top 4', with its relative importance varying. All of the results are tabulated and discussed in O' Connor and Blythe (1997).

Table 4-3 'Top 4' Requirements & Environmental Considerations (Pilot Study)

<table>
<tr><th colspan="2">Requirements</th><th colspan="2">Environmental Considerations</th></tr>
<tr><th>Open-ended
(Identification Rank)</th><th>Closed-ended
(Rank - Weight)</th><th>Open-ended
(Identification Rank)</th><th>Closed-ended
(Rank - Weight)</th></tr>
<tr><td>Unit cost</td><td>Reliability = Warranty</td><td>Ergonomics</td><td>Safety</td></tr>
<tr><td>Reliability</td><td rowspan="3">Repairable = Quality</td><td>Upgradeability</td><td>Reliability</td></tr>
<tr><td>Upgradeability</td><td rowspan="2">Safety = Usability</td><td>User Satisfaction</td></tr>
<tr><td>Performance = Aesthetics = Screen Resolution</td><td>Occupational Health</td></tr>
</table>

A summary of the general environmental views of all participants is provided in Table 4-4. Although none of the participants subscribe to environmental groups, they claimed to have a high concern with environmental issues[8]. Their willingness to participate in take back schemes at the end of the PCs useful life was based on the costs being built in to the product on initial purchase. Only 14% of the participants would be prepared to rent or lease the products instead of outright purchase. Such schemes have worked successfully with other products but for these users of PCs owning the system was a necessity. Participants' willingness to pay, on average, 6% more for products with perceived environmental benefits was much lower than the figure of 13% quoted by Mintel, cited in Burall (1996) in 1994 study of the U.K. Some of the participants claimed they would only pay extra for environmental benefits that would be of direct benefit to them; either in terms of long-term cost savings or enhanced performance. 88% of the participants wanted companies to provide background environmental information on their products. Some of them suggested a single sheet would be sufficient, with an analysis of the product against the most important environmental criteria determined by the key stakeholders. This would be complete by an independent assessment body. This is quite similar to the study by Mintel, cited in Burall (1996), where 88% of participants said that manufacturers were not providing enough information with their products.

Table 4-4 General Environmental Views of Participants (Pilot Study)

Willingness to pay extra for products with environmental benefits Percentage extra	100% 6%
Willingness to participate in product return schemes	100%
Willingness to rent/lease products instead of outright purchase	14%
All companies should provide environmental information on their products	88%

[8] On a scale of 0 (no concern) to 4 (high concern) the participants averaged '3' on a local, national and global level.

4.3 Initial Conclusions of Pilot Study

The study achieved its aims, verifying the chosen techniques through establishing a preliminary user 'body of knowledge'. The study indicated that the stakeholder grouping of users have a role to play in helping to develop an abridged approach, through providing their views and opinions on the key environmental considerations for the products. The structure and wording of the questionnaire was confirmed for gathering the general views and opinions of stakeholders. The study also confirmed that questionnaires, with an explanatory note, were a more suitable technique than interviews, for gathering general information from a large group of participants.

4.3.1 Feedback

The participants found the study helpful through encouraging them to consider environmental issues. They expressed difficulty in applying the ranking system of must/want/wish criteria. It was decided it would be sufficient to use a weighting system in the main study. During the informal interviews a lot of discussion centered on additional issues not raised in the questionnaire. These included the need for ECD legislation and the role of various stakeholders in pushing and deciding the importance of environmental issues. As a result it was resolved to include supplementary questions in the main study to investigate these issues.

Views from Industry

The results were presented to one of the collaborating companies and produced positive feedback. The identification of traditional design requirements such as ergonomics and reliability as key environmental considerations was found to be of special interest. Some concern was raised over the wide range of considerations identified by such a small number of participants, and the complexity of considering all of them in an abridged approach. As there were similar requirements and considerations listed, i.e. ease of use and user-friendliness, it was decided to group them into broad categories thus simplifying the application of the results in an abridged approach.

4.4 Categorization of Requirements

It was possible to group the 37 product requirements identified into 10 broad categories, Table 4-5. These are not presented in any particular order of importance.

Table 4-5 Requirement Categories

1	'Green' Issues, i.e. recycleability of product, etc.
2	Quality & Reliability during usage, including performance, efficiency, etc.
3	Health & Safety during usage, i.e. radiation, noise, etc.
4	Human Factors during usage, i.e. ergonomics, user friendly, etc.
5	Physical Properties, i.e. weight, size, etc.
6	Service Issues, i.e. ease of repair, upgradeability, etc.
7	Features/Functionality, i.e. speed, adaptability, etc.
8	Product Cost, i.e. cost to purchase and operate, etc.
9	Aesthetics of product, i.e. visual appearance, etc.
10	Supplier Support, i.e. provision of information, etc.

4.5 Categorization of Environmental Considerations

16 broad categories were formed from the 46 environmental considerations identified, Table 4-6. Again, these are not presented in any particular order of importance.

Table 4-6 Environmental Categories

1	Product Energy, i.e. energy consumption of product during usage.
2	Product Recycling, i.e. recycleability of product.
3	Material Issues (including Resource & Component issues), i.e. selection, standardization, minimization, non-toxic, renewable etc.
4	Quality & Reliability during usage include. Performance, efficiency, etc.
5	Health & Safety during usage, i.e. radiation, noise, etc.
6	Human Factors during usage, i.e. ergonomics, user friendly, etc.
7	Physical Properties, i.e. weight, size, etc.
8	Service Issues, i.e. ease of repair, upgradeability, etc.
9	Manufacturing Issues, i.e. waste, energy, labor, costs, assembly, location, etc.
10	Features/Functionality, i.e. speed, adaptability, etc.
11	Sustainable, i.e. self-sustaining, satisfying real needs, quality of life, etc.
12	Product Cost, i.e. cost to purchase and operate, etc.
13	Packaging Recycling, i.e. recycleability of packaging.
14	Aesthetics of product, i.e. visual appearance, etc.
15	Disposal Issues, i.e. issues associated with product disposal.
16	Multiple Life Cycle Issues, i.e. remanufacture and reuse of product, etc.

4.6 Weighting of Categories

Using the pilot study results it was possible to achieve a preliminary set of weightings for these categories based on three methods:

Weighting Method A: The number of times the requirements or considerations in each category were identified in the open-ended sessions as a percentage of the total number of requirements or considerations identified.

Weighting Method B: The number of times the categories were identified in the open-ended sessions as a percentage of the total number of categories identified.

Weighting Method C: The average rank-weight score from the closed-end sessions as a percentage of the total average rank-weight score. The rank-weight score is the product of the rank and weight scores respectively.

Examples of each weighting method for one environmental category, 'Material Issues', are provided in Table 4-7.

Table 4-7 Weighting of 'Material Issues' Category

(i) Method A

Number of Times Material Considerations Identified	Total Number of Times all Considerations Identified	Percentage of Total (%)
17	146	11.6

(ii) Method B

Number of Times Materials Category Identified	Total Number of Times all Categories Identified	Percentage of Total (%)
8	81	9.9

(iii) Method C

Average Rank-Weight Score of Material Category	Total Average Rank-Weight Score of all Categories	Percentage of Total (%)
3	78	3.9

4.7 Profiling of Categories

It was then possible to profile the categories based on the weightings from these three methods. The three methods produce different category weightings that could be used in an abridged approach. Although the weightings are calculated as percentages they could also be computed on a scale of '0 to 10'. The top requirement and environmental categories from each weighting method are given in Table 4-8. As the weightings have been developed from a limited sample size of stakeholders the method of analysis is more important than the actual results.

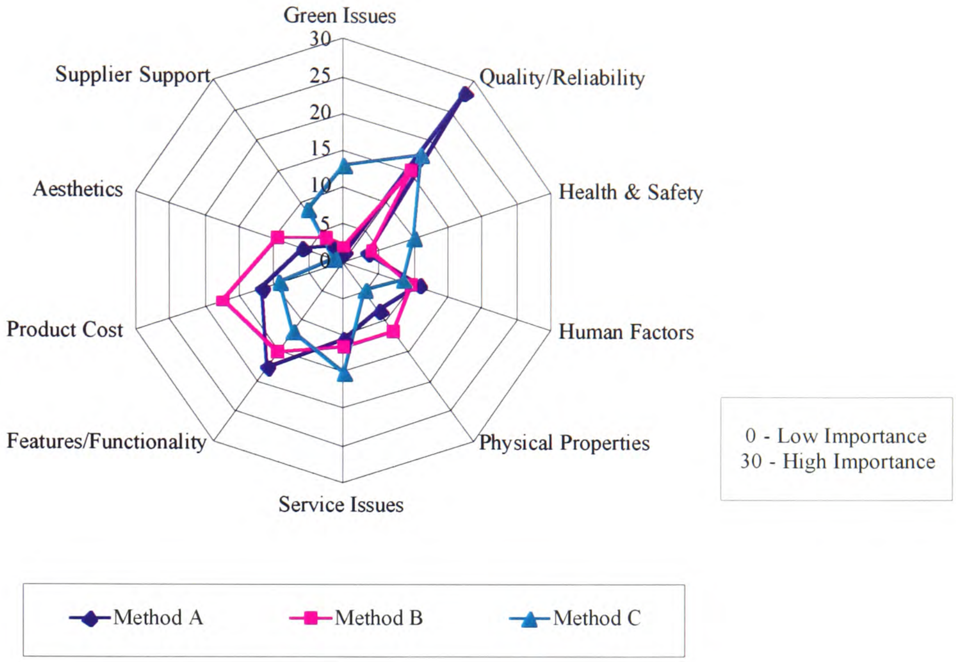

Figure 4-2 Profiling of Requirement Categories (Pilot Study)

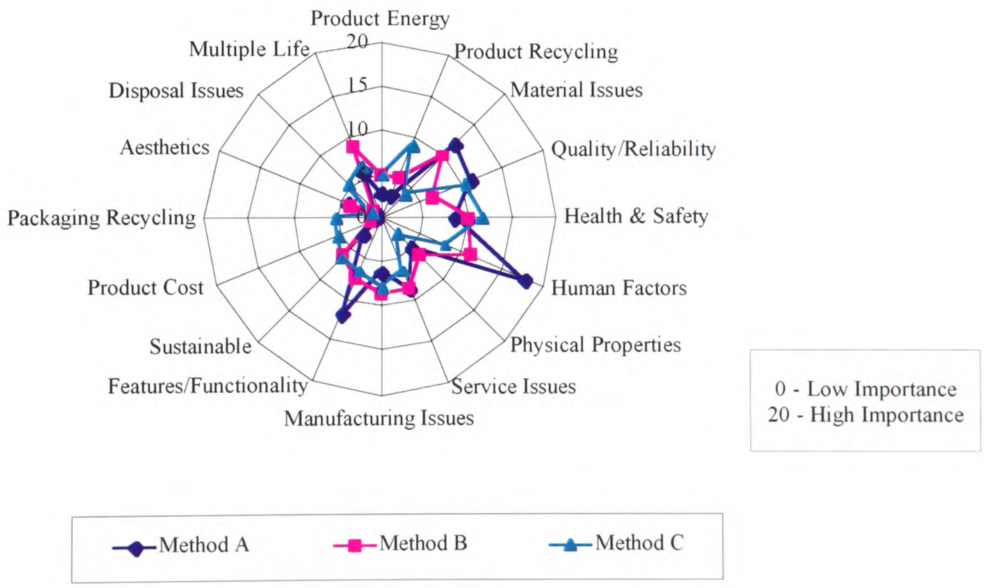

Figure 4-3 Profiling of Environmental Categories (Pilot Study)

Table 4-8 Top Categories from Weighting Methods (Pilot Study)

Category	Method A	Method B	Method C
Requirement	Quality/Reliability	Product Cost	Quality/Reliability
Environmental	Human Factors	Human Factors	Health & Safety

4.8 Matrix Analysis

A number of categories, such as 'human factors' and 'quality and reliability' are common to both lists. These are highlighted in Table 4-9.

Table 4-9 Common & Additional Categories

Requirements Categories	**Environmental Categories**
'Green' issues	
Quality & Reliability during usage	Quality & Reliability during usage
Health & Safety during usage	Health & Safety during usage
Human Factors during usage	Human Factors during usage
Physical Properties	Physical Properties.
Service Issues	Service Issues
Manufacturing Issues	(Environmental) Manufacturing Issues
Features/Functionality	Features/Functionality
Product Cost	Product Cost
Aesthetics of product	Aesthetics of product
Supplier Support	
	Product Energy
	Product Recycling
	Material Issues
	Sustainable
	Packaging Recycling
	Disposal Issues
	Usage Resource Consumption
	Shipping & Storage Issues
	Multiple Life Cycle Issues

A quick and effective methodology for analysis could be to focus on the requirement, and environmental or 'green' issues together using a matrix approach, Figure 4-4. To facilitate this it was decided to distinguish between manufacturing issues and environmental manufacturing issues through having two separate categories – 'environmental manufacturing' and other 'manufacturing issues'. The 'manufacturing issues' category includes requirements such as manufacturing costs and methods of assembly. This further categorization simplifies the scoring of the categories. Also, although they had not been identified as important in the pilot study it was decided appropriate to provide separate categories for 'usage resource consumption' and 'shipping and storage'. The former becomes a key category when devices, which consume resources during usage, are considered, i.e. computer printers consume large quantities of ink and paper. 'Shipping and storage' issues become a key category for products that require being shipped long distances and stored for long period of times. All the additional categories are bolded in Table 4-9. 'Supplier support' was not added to the matrix as it involves providing a service and is not regarded as a specific product requirement. The categories are not presented in any particular order of importance in the matrix.

4.9 Explanation of Matrix Method

The matrix (Figure 4-4) is constructed of a number of columns: 'environmental categories', 'weight', 'score', and 'weight.score', which are the product of the weight and the score. SLC and MLC products are clearly distinguished in the matrix. The matrix should be complete as early as possible in the design process, preferably as part of a GCE program using a multi-functional LCT. The weightings from the survey would be included in the column 'weight'. A qualitative score, i.e. from 0 (no concern) to 10 (very high concern), would then be assigned to each of the categories and included in the appropriate column. The results could be profiled using a target plot to prioritize categories, benchmark products and pinpoint areas for improvement.

No	Environmental Category	Weight	Score	Weight.Score
1	Product Energy			
2	Product Recycling			
3	Material Issues			
4	Quality & Reliability			
5	Health & Safety			
6	Human Factors			
7	Physical Properties			
8	Service Issues			
9	Environmental Manufacturing			
10	Features/Functionality			
11	Sustainable			
12	Product Cost			
13	Packaging Recycling			
14	Aesthetics			
15	Disposal Issues			
16	Usage Resource Consumption			
17	Shipping & Storage			
18	Other Manufacturing Issues			
Total Weight.Score (Single Life Cycle) or TWS_{SLC}				
19	Multiple Life Cycle Issues			
Total Weight.Score (Multiple Life Cycle) or TWS_{MLC}				

Figure 4-4 Matrix Method (Pilot Study)

4.10 Final Conclusions of Pilot Study

The pilot study achieved its aims while also providing a methodology for analyzing the results in the main study. A preliminary 'body of knowledge' from one key stakeholder grouping, 'users', was gathered for PCs. A methodology for integrating this 'body of knowledge' into an abridged ECD process has also been developed through a matrix based approach. The approach considers the views of a range of stakeholders and examines MLC options. The next stage of the research focuses on gathering the 'body of knowledge' from a range of stakeholders for PCs, electromechanical products and packaging.

5 Results and Discussion of Main Study

This chapter presents and discusses the research results for the main study. The main study involved gathering a 'body of knowledge' from a range of stakeholders via surveys and industrial case studies of PCs, electromechanical products and packaging. It includes an in-depth look at the EOL asset management of electromechanical products.

5.1 PCs

This section involved the collection of a 'body of knowledge' through four surveys and two industrial case studies of PCs. A simplified research approach for PCs is given in Figure 5-1.

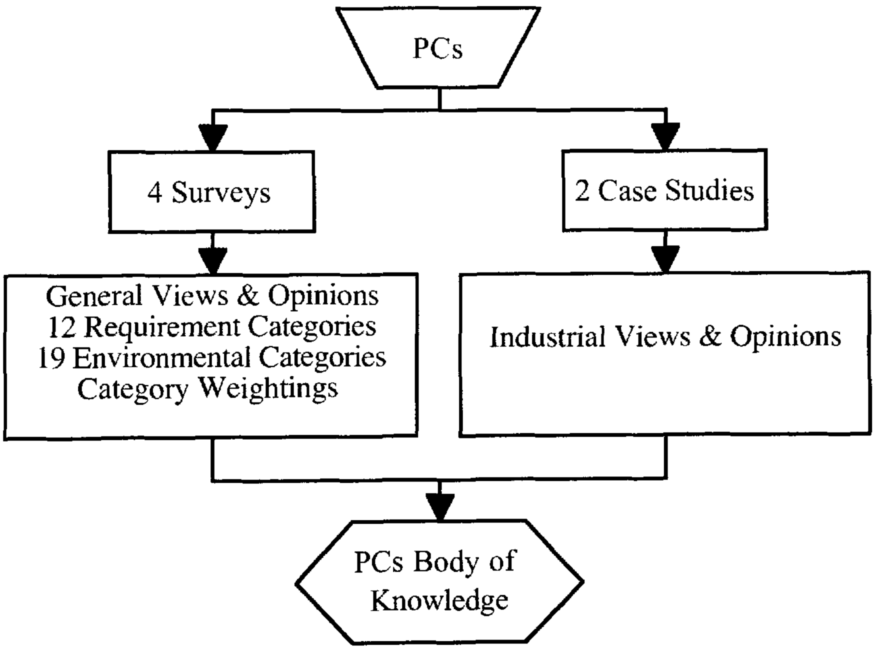

Figure 5-1 Simplified Research Approach for PCs

The main aims of the surveys were:

- To identify and group key requirements and environmental considerations for PCs into a list of categories
- To provide relative weightings, focusing on the environmental categories[9]

Details of the four surveys (A – D) are given in Table 3-2.

5.1.1 Survey A: Range of Stakeholders / PCs

This survey of a wide range of stakeholders for PCs, included participants from the collaborating companies and their stakeholders. The primary aim of this phase was to identify and group key requirements and environmental considerations for PCs through open-ended questioning. An initial weighting of their relative importance was carried out simultaneously. Secondary aims included gathering information on the general views of participants on a range of issues. The postal questionnaire (with an explanatory note) contained a combination of open-ended and closed-ended questions, Appendix A. Through open-ended questions participants were asked to identify their key product requirements and environmental considerations before weighting them. The closed-ended 'Yes/No' type questions were used to gather general participant views on issues such as their role in ECD, and their willingness to pay extra for products with perceived environmental benefits. Draft versions of the questionnaires were tested during the pilot study (Chapter 4) until there was a clear understanding of all sections. Questionnaires were sent to over 300 people from a range of stakeholder groupings. Collaborating computer companies and their stakeholders were targeted. Apple, Sony, Alps were among the companies who actively participated in the survey. Other stakeholder groupings such as environmentalists, users and the general public were randomly chosen from various databases. 123 participants of 20 different nationalities returned the questionnaire. 62% of these resided in the U.K., 24% in other European

[9] In surveys B to C relative weightings were developed for the environmental categories.

countries, 7% in the USA and 7% in other countries. A simplified breakdown of the population, using Table 1-1, is provided in Table 5-1. The population is predominantly users (62.6%) and producers (29.3%).

Table 5-1 Breakdown of the Population for Survey A

Stakeholder Grouping	%
Government	1.6
Producers	29.3
Users[10]	62.6
Environmentalists	1.6
Others	4.9

5.1.1.1 General Environmental Information

A summary of the general environmental views of all participants is provided in Table 5-2. Although only 11% of the participants subscribe to environmental groups such as 'Greenpeace' and 'Friends of the Earth', they claimed to have a high concern with environmental issues[11].

Table 5-2 General Environmental Views of Participants in Survey A

Willingness to pay extra for products with environmental benefits	71%
Percentage extra	13%
Willingness to participate in product return schemes	77%
Don't know	18%
Willingness to rent products instead of outright purchase	31%
Don't know	31%
Willingness to lease products instead of outright purchase	31%
Don't know	35%
All companies should provide environmental information on their products	77%
Don't know	1%
ECD legislation is required	72%
Don't know	14%

[10] 9% of this grouping were 'general public'.
[11] On a scale of 0 (no concern) to 4 (high concern) the participants averaged '3' on a local, national and global level.

71% of the participants pledged to be willing to pay, on average, 13% more for products with perceived environmental benefits. This is the same as the figure quoted by Mintel, cited in Burall (1996) in her 1994 study of the U.K[12]. This indicates that ECD is a worthwhile exercise. 77% of participants declared to be willing to participate in product return similar to those presently available for glass and plastic containers thus facilitating EOL asset management. Only 31% of the participants claimed to be prepared to rent or lease the products instead of outright purchase. Such schemes have worked successfully with other products, most notably telephones. For PCs owning the system seems to be an important criteria.

Provision of Environmental Information

77% of the participants declared a wish for companies to provide background environmental information on their products. 'Product recycling', 'material issues', 'health and safety' and 'manufacturing issues' are the considerations that participants require most information on, Figure 5-2.

[12] In the study by Mintel 100% of the participants resided in the U.K (Burall, 1996).

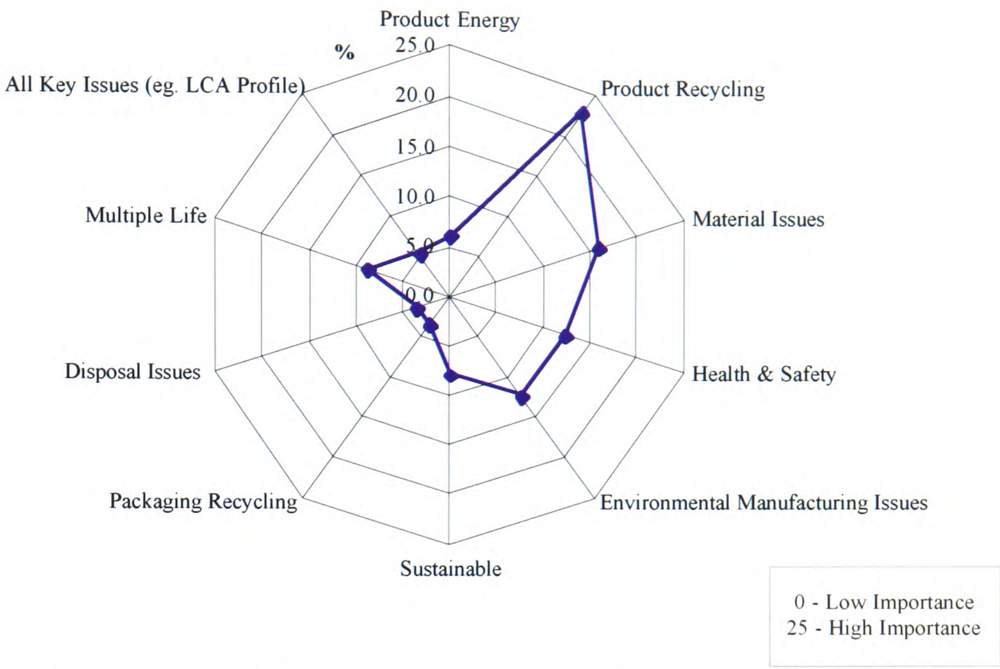

Figure 5-2 Issues That Companies Should Provide Environmental Information On

This is similar to the study by Mintel, cited in Burall (1996) where 88% of participants said that manufacturers were not providing enough environmental information with their products.

Need for Legislation in ECD

72% of participants felt there was a need for specific legislation in ECD. As per the request for environmental information, 'product recycling', 'material issues', 'health and safety' and 'manufacturing issues' are the environmental considerations participants want the legislation to predominantly focus on, Figure 5-3.

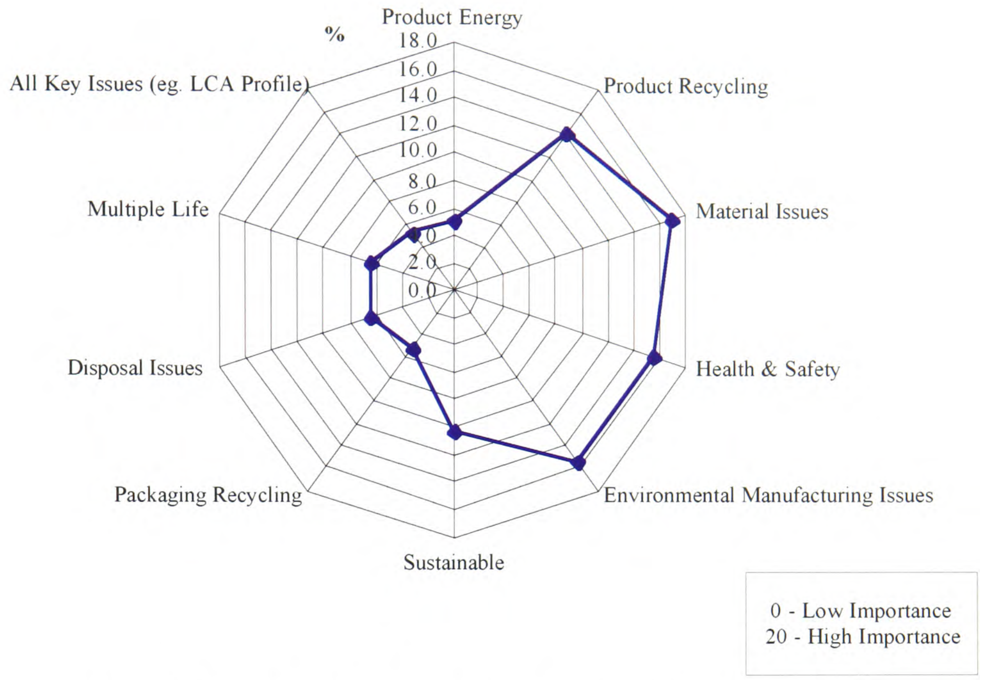

Figure 5-3 Specific Issues for ECD Legislation to Cover

Some of the participants volunteered some suggestions on the type of legislation that would be appropriate. Comments included: "… the legislation should be mandatory with heavy penalties, use standard metrics, ensure misleading claims are banned, have a monitoring mechanism, and link to existing standards such as quality". Other options suggested included government subsidies and tax incentives for companies who focus on improving their environmental performance.

Role to Push Environmental Issues

On average the participants felt that the government should adopt the main role in pushing environmental issues as key criteria. When 16 ECD experts were asked the same question they also selected the government[13]. The key difference between both surveys was that the range of stakeholders also placed secondary emphasis on the role of the producers while the ECD

[13] Details of this survey can be found in Section 5.2.5

experts selected users, Figure 5-4. These results have extra significance when it is remembered that the stakeholders in this survey were predominantly users (63%). Also, the ECD experts preferred to place the responsibility with users, rather that their own stakeholder grouping, environmentalists.

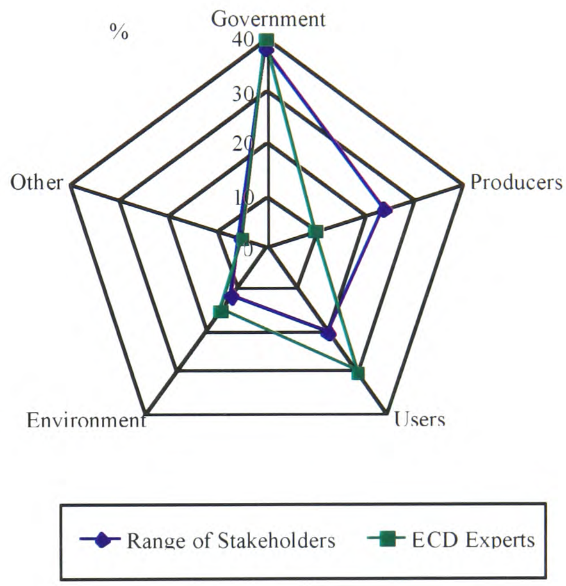

Figure 5-4 Role to Push Environmental Issues

Role to Decide Importance of Environmental Issues

The participants felt that the government and users should have the biggest role in determining the importance of environmental issues. When the 16 ECD experts were asked the same question they made similar selections, Figure 5-5.

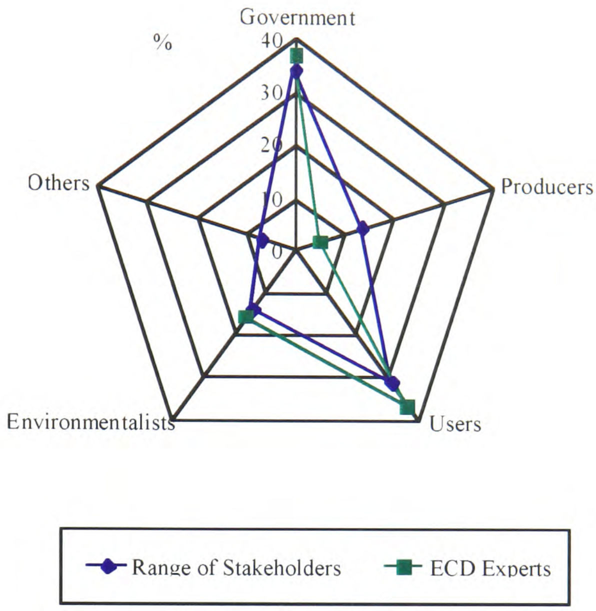

Figure 5-5 Role to Decide Importance of Environmental Issues

5.1.1.2 Categorization and Weighting of Requirements

Following the approach implemented in the pilot study, it was possible to group the requirements into 12 broad categories. The 2 additional categories were '(other) manufacturing issues' and 'product type/brand name', Table 5-3. The original categories are given in Table 4-5.

Table 5-3 Additional Requirement Categories

1	(Other) Manufacturing Issues, i.e. labor issues, costs, assembly, location, etc.
2	Product Type/Brand, i.e. brand name, etc.

The categories were firstly weighted based on 'Weighting Method A' from the pilot study with the most frequently identified ones being 'features and functionality', 'quality and reliability' and 'human factors'. The requirements were then weighted based on the average, mode and median-using Table 5-4 with similarly high weightings produced by each technique, with no significant variation. The only exception was the 'other manufacturing issues' modal value which had a variation of greater than 4. In these surveys a significant variation is defined as 'greater than 2.5' on the scale in Table 5-4. This value was devised through giving a practising product engineer the same list of environmental categories twice over a 1-year interval. Some of the category weightings varied by a value of 2 thus 'greater than 2.5' was selected as a significant variation.

Table 5-4 Weighting Scale (0-10)

0	2	4	6	8	10
Not Important	Very Low Importance	Low Importance	Medium Importance	High Importance	Very High Importance

'Weighting Method A' produced a noticeably different profile to the 'average weighting'. This variation is illustrated in Figure 5-6, with the 'average weighting' presented as a percentage of the total weight. This is partly due to some participants identifying the key issues but not weighting them. These weightings include the selections of all the stakeholders who participated. The results indicate that different requirement weightings are achieved through using different weighting methods.

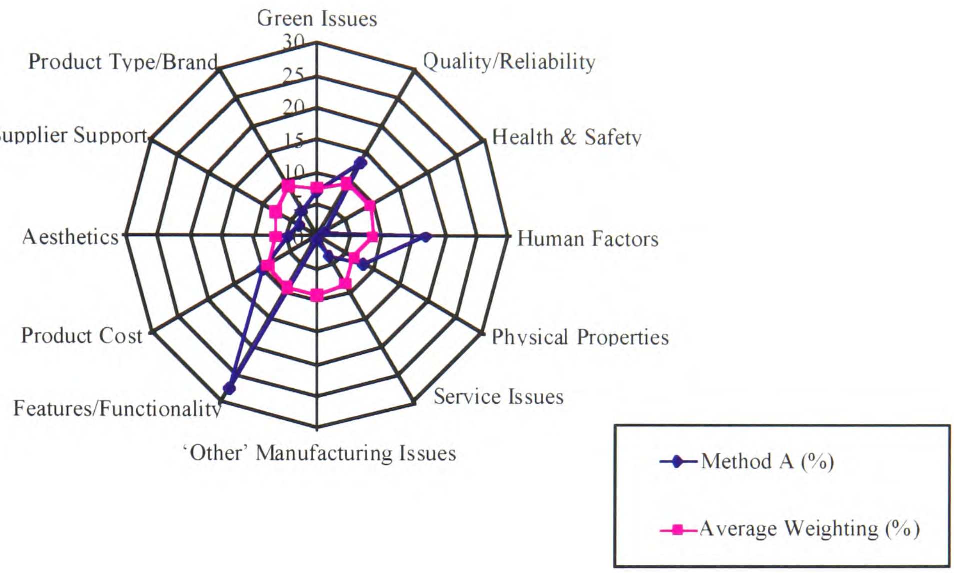

Figure 5-6 Weighting Profiles of Requirements (Survey A)

5.1.1.3 Categorization and Weighting of Environmental Consideration

Following the approach implemented in the pilot study it was possible to group the environmental issues into 19 broad categories. As proposed in Section 4.8, the 'manufacturing issues' category was separated into two: 'environmental manufacturing' and '(other) manufacturing issues'. The other additional categories were 'usage resource consumption' and 'shipping and storage', Table 5-5. The original categories are given in Table 4-6.

Table 5-5 Additional Environmental Categories[14]

1	Environmental Manufacturing Issues, i.e. waste, pollution, energy, etc.
2	Usage Resource Consumption, i.e. water, paper, etc.
3	Shipping & Storage Issues, i.e. type of transport, etc.
4	Other Manufacturing Issues, i.e. labor issues, costs, assembly, location, etc.

[14] In the pilot study 'environmental manufacturing issues' and 'other manufacturing issues' were grouped together.

The environmental categories were again weighted using 'Weighting Method A', with the most frequently identified category being 'material issues'. Others that featured prominently included 'aesthetics', 'product recycling', 'quality and reliability' and 'health and safety'. The categories were also weighted based on the average, mode and median with similar high weightings produced by each technique, with no significant variation. The only exception to this was 'usage resource consumption', which was not selected. The justification for including this as a category is given in Section 4.8. 'Weighting Method A' again produced a noticeably different profile to the average weighting.

Comparing Stakeholder Grouping Selections for Environmental Categories

The selections of a few of the larger stakeholder groupings were examined to identify any notable variations. Two stakeholder groupings, 'producers' and 'users' were selected as they amounted to over 90% of the population. The significant stakeholder subset within the 'producers' group, 'designers', were also examined further, as they accounted for 64% of that respective population. Two weighting methods were applied to the environmental categories: 'Weighting Method B' from the pilot study and the 'average weighting'. Both methods produced similar weightings for 'users', 'producers' and 'all' participants with some exceptions[15]. The top categories are given in Table 5-6.

Table 5-6 Top Environmental Categories for Survey A (All, Users, Producers)

Method	All	Users	Producers (include Designers)
'Weighting Method B'	Product Energy = Product Recycling	Product Recycling	Product Energy
Average Weighting	Product Cost = Features/Functionality	Product Cost = Service = Features/Functionality	Physical Properties = Aesthetics = Multiple Life

[15] Producers had not identified 'sustainable', and both producers and users had not identified 'shipping and storage'.

Using both methods there was variation between the weightings for designers and producers (excluding designers), with the top categories given in Table 5-7. This variation was not significant.

Table 5-7 Top Environmental Categories for Survey A (Producers, Designers)

Category	Producers (excluding Designers)	Designers
'Weighting Method B'	Product Energy = Product Recycling = Human Factors	Material Issues
'Average Weighting'	Features/Functionality	Multiple Life

The 'average weighting' profiles for 'all', 'users', 'producers (excluding designers)' and 'designers' are given in Figure 5-7, and are based on Table 5-4.

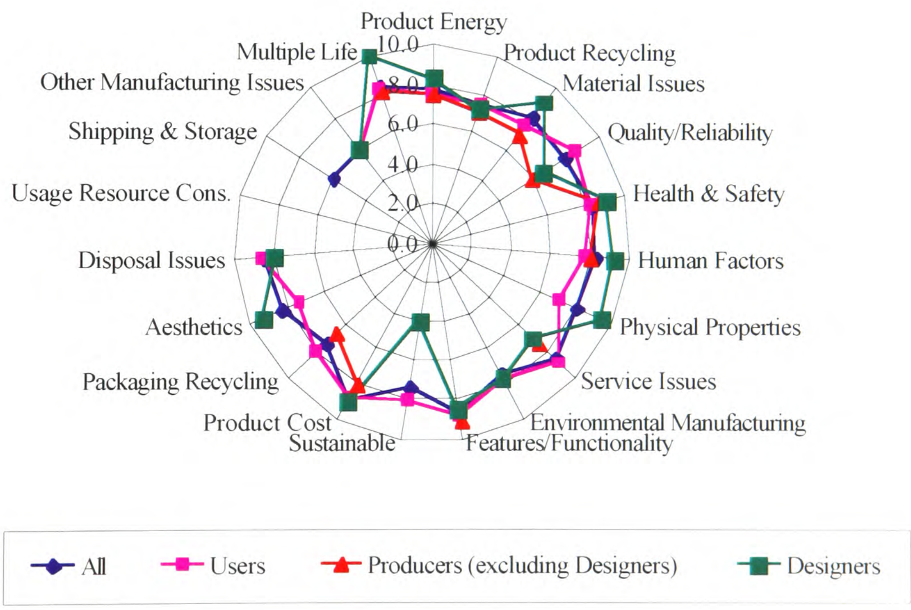

Figure 5-7 A Stakeholder Comparison: Average Weightings of Environmental Categories (Survey A)

Many of the participants identified the key requirements and environmental considerations but did not weight them. The results indicate that designers attach slightly higher weightings than other stakeholders group to most of the categories, most notably other stakeholders in the producers group. This variation was not found to be significant. Significantly designers gave an average weighting of '4' to 'sustainable' whereas users gave it '7.3'.

5.1.1.4 Conclusions from Survey A

Participants, who consisted of a range of stakeholders, claim to be willing to pay extra for PCs with environmental benefits and to participate in product return schemes. This has significant implications for the design and EOL asset management of PCs. If consumers are willing to pay extra for PCs with perceived environmental benefits then it may justify companies placing extra emphasis on ECD at the design stage. Also, if consumers are willing to participate in product take-back schemes, then EOL asset management could become more economically viable. 'Product recycling', 'material issues', 'health and safety' and 'environmental manufacturing issues' feature prominently as key environmental criteria. Participants require more information on these criteria, and want ECD legislation to focus on them. Participants expressed the view that the government should have the main role in pushing environmental criteria. In deciding their importance the government and users should have the main roles. A survey of 16 ECD experts made similar role selections. This indicates that the views of these stakeholder groupings should be weighted higher than other groupings. An example of this could be to assign weightings to the groupings based on Figure 5-5. Using the selections of participants from 'Survey A' the approximate weightings in Table 5-8 can be devised based on Table 5-4.

Table 5-8 Stakeholder Weightings (Survey A)

Stakeholder Grouping	Stakeholder Weight (SW)
Government	7
Producers	3
Users	6
Environmentalists	3
Others	1.5

These weightings could be refined through consulting other stakeholders. ECD legislation could be a suitable method for the government to push and decide the importance of environmental issues. A range of techniques including case studies, surveys and LCA data could be applied to arrive at a standard set of categories and relative weightings for this legislation.

The requirement and environmental categories from the pilot study were verified, with two additional requirement categories, and three additional environmental categories. With the exception of two: 'supplier support' and 'product type/brand', all of the requirement categories are repeated in the environmental categories thus the remainder of the study on PCs will focus on the environmental categories. 'Supplier support' and 'product type/brand', were not added to the list as they were not regarded as specific product requirements. The former involves providing a service and the latter are selling points. The survey showed that it is possible to determine weightings for different stakeholder groupings. Different weighting methods can result in different profiles. No significant variation was found between the participant 'average weighting' of the requirement categories and their weighting of those that were repeated in the environmental categories. The 'average weighting' technique was preferred for the remainder of the study on PCs. The results indicate a difference in opinions between designers and other stakeholder groupings when weighting the environmental categories. The designers who participated in the survey applied higher weightings to most categories. These variations were not significant. The weightings could be applied directly to a matrix for PCs using the methodology outlined in the pilot study, Figure 4-4. The environmental performance of the PCs could be then improved based on stakeholder preference. Finally, the study had a number of limitations. As the session was open-ended many of the participants identified the key requirements and environmental considerations but did not weight them. This affected the final weighting profiles as some categories were not weighted. Also, the sample population was predominantly users, while the approach aims to include all key stakeholder views.

5.1.2 Survey B: Range of Stakeholders / PCs

This phase involved getting members of the Alps CFT and some of their external stakeholders to confirm and weight the key environmental categories identified in the open-ended sessions, by completing a closed-ended questionnaire. The primary aim of this phase was to confirm the environmental categories for PCs along with carrying out some weighting of their relative importance. The closed-ended questionnaire (Appendix A) was presented to members of the Alps CFT and Alps external stakeholders. Participants were asked to confirm the key environmental categories before weighting them. 18 of the 30 stakeholders targeted completed the survey. These were as follows: 2 marketing personnel, 5 designers, 2 suppliers, 1 sub/contractor, 1 purchasing member, 2 manufacturing members, 2 users, 2 service and an environmentalist.

5.1.2.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. These environmental categories were then weighted using the scale in Table 5-4. 'Quality and reliability' and 'sustainable' came out as the top categories, Figure 5-8. Upon further analysis designers, who accounted for over 25% of the participants, weighted all the categories slightly higher than the rest of the participants. 'Health and safety', 'disposal issues' and 'usage resource consumption' were weighted significantly higher. When the designers were questioned further they claimed to be uneasy applying one weighting per category. They preferred to be given the option to apply two weightings: a high 'ideal' value (which they had applied in the survey), and a lower 'actual' value, which was representative of what they applied in industrial practice. When completing the questionnaire two of the designers had divided the weighting column into 2 options, 'ideal' and 'actual'. Ideally, these two designers would like to place high emphasis on considerations such as 'multiple life' and 'product recycling' but in practice this is not always possible due to ever shortening product development times and cost constraints. In reality, to survive in such a competitive climate, companies need to develop cost-effective concepts that satisfy market requirements, before they can place emphasis on environmental factors. This is demonstrated in Figure 5-9 for questionnaires completed by a mechanical and product designer.

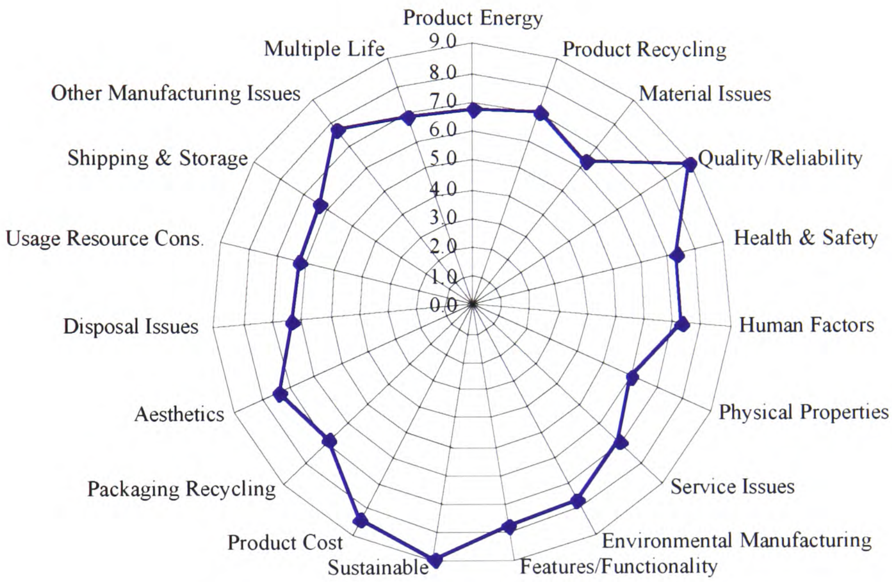

Figure 5-8 Average Weightings Profile (Survey B)

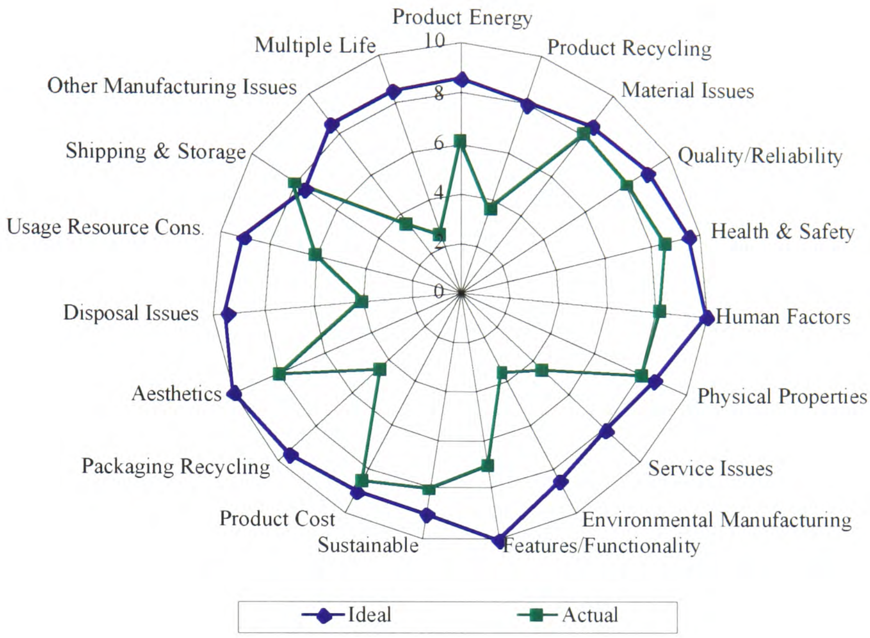

Figure 5-9 Average 'Ideal' and 'Actual' Weightings for 2 Designers (Survey B)

Significant variations are evident in 'product recycling', 'service', 'environmental manufacturing', 'features/functionality', 'packaging recycling', 'disposal, 'usage resource consumption', 'other manufacturing issues' and 'multiple life'.

5.1.2.2 Conclusions from Survey B

The environmental categories were re-verified. Industrial weightings have been identified for PCs although a significant variation was noted between designers 'actual' and 'ideal' weightings with the former significantly lower for nine categories. Thus although stakeholders may consider a category to be important they will not necessarily assign importance to it in industrial practice. This may be partially attributed to the fact that they were a task-focused department.

5.1.3 Survey C: Trainee Product Designers / PCs

This phase involved getting 4 trainee product designers to confirm and weight the key environmental categories identified in the open-ended sessions, by completing a closed-ended questionnaire[16]. The primary aim of this phase was to confirm the environmental categories for PCs along with carrying out some weighting of their relative importance. The closed-ended questionnaire (Appendix A) was presented to the group. Participants were asked to confirm the key environmental categories before weighting them. Individually, the participants had previously carried out a twelve-week ECD analysis and improvement study of the products using a range of abridged techniques including checklists, flow diagrams, matrices and profiles. The students were encouraged to use formats similar to those outlined in Figure 5-15 and Figure 5-55. From the study they developed environmentally conscious concepts. The products selected were a computer monitor, mouse, printer and digital camera.

5.1.3.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. The categories were weighted using the scale in Table 5-4. The 'average weightings' are profiled in Figure 5-10 with 'product recycling', weighted '9', being the top category.

[16] The participants were final year students from the 'Product Design' degree courses at the UOG.

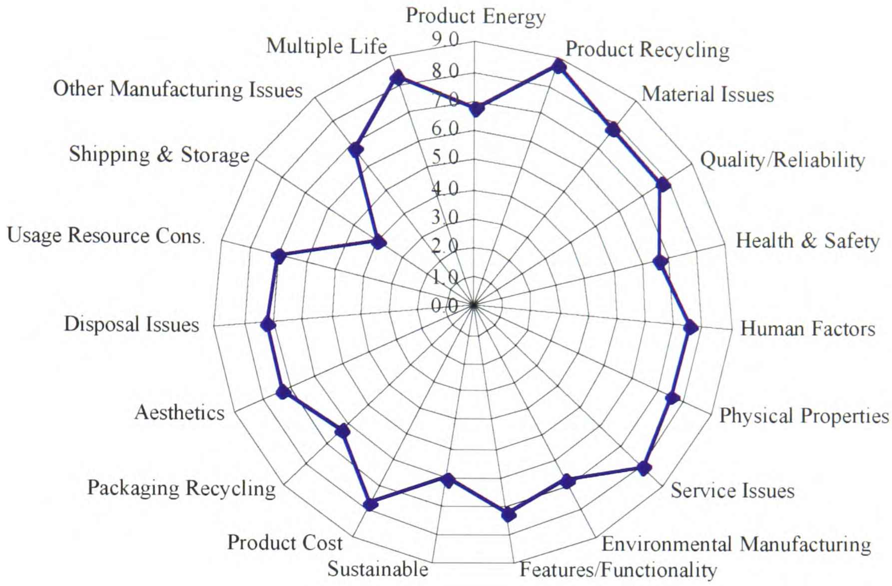

Figure 5-10 Average Weighting Profile (Survey C)

5.1.3.2 Conclusions from Survey C

The list of environmental categories has been re-verified and a series of weightings have been identified for PCs.

5.1.4 Survey D: ECD Experts / Computer Keyboard

This survey formed part of a focus group and involved getting 4 ECD experts to confirm and weight their environmental categories for one PC product, a computer keyboard. The background and main aims of the focus group are outlined in Section 5.2.5, with the questionnaire given in Appendix A. For the purpose of this survey the aim was to get the group to confirm and weight the environmental categories for a computer keyboard. A secondary aim was to compare the views and opinions of the ECD experts. The participants were presented with the list of environmental categories and asked to go through the following procedure, Table 5-9.

Table 5-9 A Procedure for Selecting 'Top 5' Categories

Step 1	Confirm the categories were applicable to the computer keyboard.
Step 2	Individually select the 'Top 8' environmental issues for their assigned product.
Step 3	As a group, gain consensus on the 'Top 5' environmental categories.
Step 4	Individually weight the 'Top 5' categories in terms of overall importance using Table 5-4.
Step 5	As a group, gain consensus on the 'Top 5' weightings.

5.1.4.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. These group weightings are compared against the individual ones for the 'top 5' categories in Figure 5-11. The participants also felt that 'multiple life cycle issues' would become one of the top categories over the next 10 years.

Comparing Views and Opinions of ECD Experts

In terms of identifying and weighting the key environmental criteria, the views and opinions of ECD experts were found to be different. Although all the participants confirmed the categories their individual 'top 5' differed. In weighting the criteria, three of the respondents had quite similar results while the fourth was significantly different in all categories, with one exception, 'environmental manufacturing'.

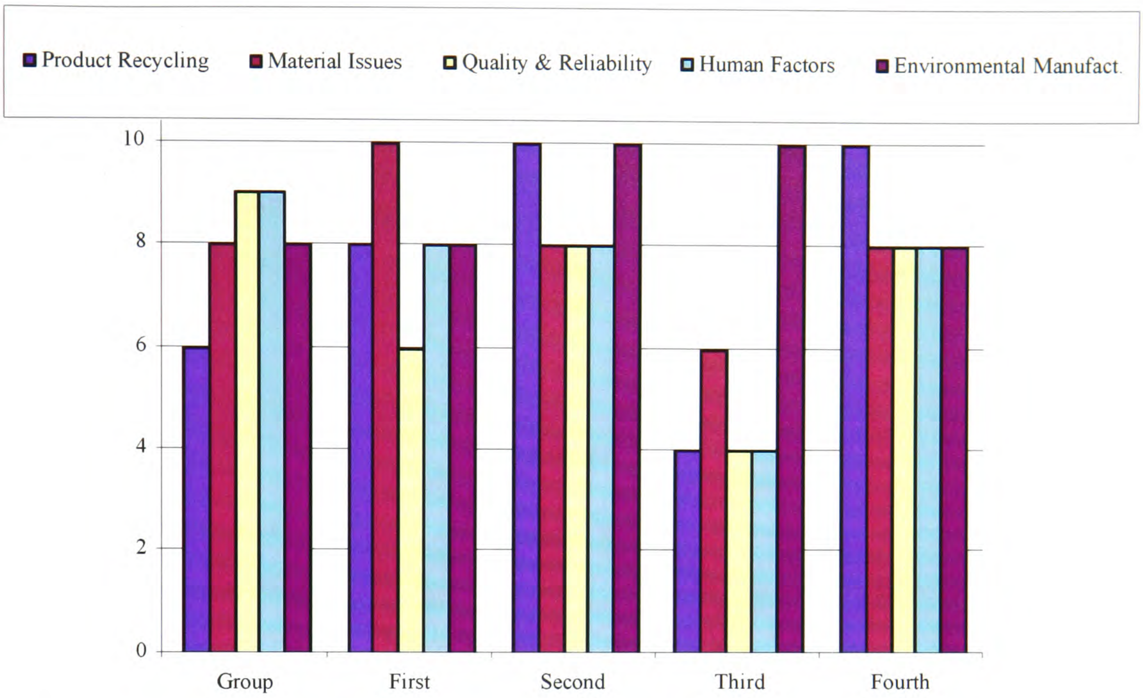

Figure 5-11 'Top 5' Category Weightings for a Computer Keyboard (Survey D)

5.1.4.2 Conclusions from Survey D

The list of environmental categories has been re-verified and a series of weightings have been identified for a computer keyboard. In terms of identifying and weighting the 'top 5' environmental criteria, the views and opinions of ECD experts were found to be different. It should be noted that the participants had a limited time frame to make decisions, and respondents with stronger opinions may have overly influenced the group decisions.

5.1.5 Summary of PCs Surveys

The general environmental information was summarized in Section 5.1.1.4. The requirement and environmental categories were verified. The requirement categories were repeated in the list of environmental categories with two exceptions, 'supplier support' and 'product type/brand'. Therefore, the matrix approach outlined in the pilot study can be applied. For the closed-end surveys, only the environmental categories were offered to participants for confirmation and weighting. The environmental categories identified were verified in all of the closed-end surveys. Ranges of preferences concerning the importance of the environmental categories were evident from the participants. Only one significant variation was evident on the average weightings for all participants in 'Surveys A, B and C'. 'Sustainable' scored '8.9' in 'Survey B' and '6' in C.

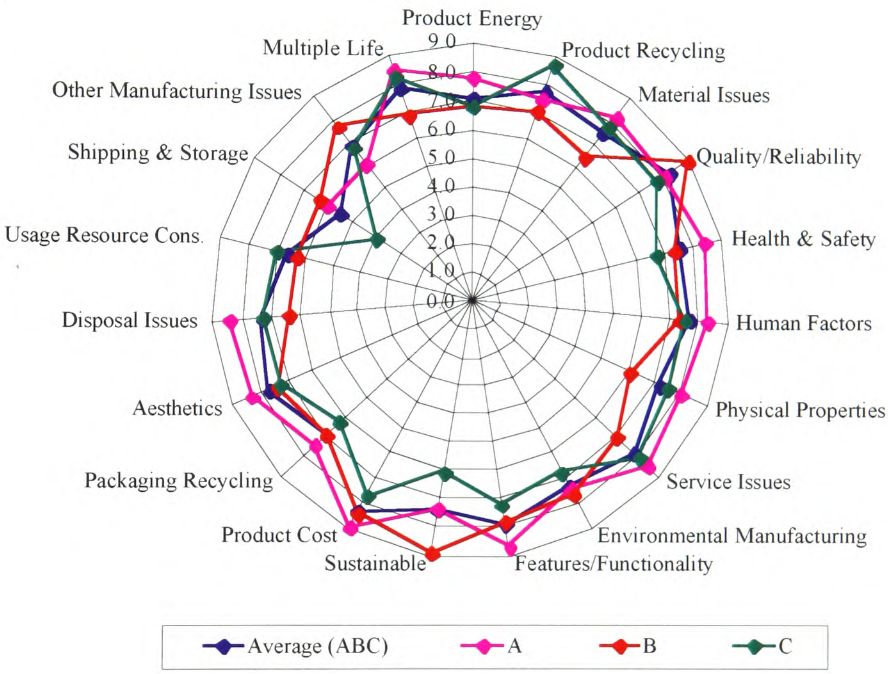

Figure 5-12 Average Weighting Profiles for Surveys A, B and C

When the ECD experts are included one significant variation is evident in the consensus weighting and the average weighting for C. 'Product recycling' scored '6' in 'Survey D' (consensus) and '8.8' in C. The profiles of the average ABC and D (consensus) are given in Figure 5-13.

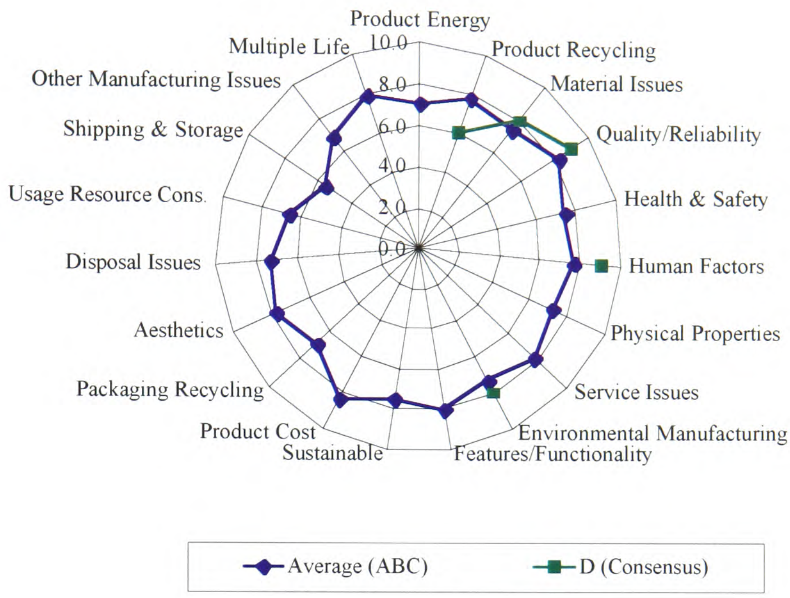

Figure 5-13 Average Weighting Profiles for ABC and Survey D

Taking the 'average weighting' the top category for each survey is given in Table 5-10[17]. 'Quality and reliability' appears in the 'top 5' categories for 'Surveys B, C and D'. The selection of reliability as one of the top categories is consistent with the work of Rothwell and Gardiner (1984).

Table 5-10 Top Environmental Categories – Surveys A to D

Survey A	Survey B	Survey C	Survey D
Product Cost = Features/Functionality	Quality/Reliability	Product Recycling	Quality/Reliability = Human Factors

[17] The top categories for 'Survey D' are based on the consensus weighting.

Weightings ABCD can be applied in the approach outlined in the pilot study to develop environmentally conscious PCs in terms of stakeholder preference[18]. Stakeholder groupings could be differentiated between through including the weightings in Table 5-8. This would mean devising separate category weightings for 'government', 'producers', 'users', 'environmentalists and 'others' and then applying them in a series of matrices. An example of a possible 'users' environmental matrix is given below, where the LCT decides the score.

No	**Environmental Category**	**$Weight_{Users}$**	**$Score_{LCT}$**	**$Weight_{Users}.Score_{LCT}$**
1	Product Energy			
2	Product Recycling			
3	Material Issues			
4	Quality & Reliability			
5	Health & Safety			
6	Human Factors			
7	Physical Properties			
8	Service Issues			
9	Environmental Manufacturing			
10	Features/Functionality			
11	Sustainable			
12	Product Cost			
13	Packaging Recycling			
14	Aesthetics			
15	Disposal Issues			
16	Usage Resource Consumption			
17	Shipping & Storage			
18	Other Manufacturing Issues			
Total $Weight_{Users}.Score_{LCT}$ (Single Life Cycle) or $TWS_{SLC(Users)}$				
19	Multiple Life Cycle Issues			
Total $Weight_{Users}.Score_{LCT}$ (Multiple Life Cycle) or $TWS_{MLC(Users)}$				

Figure 5-14 'Users' Environmental Matrix

[18] These would include the average weighting from surveys A, B and C and the consensus weighting from D.

Thus the ECD or 'green' measure of a SLC product could be got through using the following equation, using the stakeholder SLC scores and using the stakeholder weightings in Table 5-8:

$$ECD_{SLC} = SW_{Government}\,(TWS_{SLC(Government)}) + SW_{Producers}\,(TWS_{SLC(Producers)}) + SW_{Users}\,(TWS_{SLC(Users)}) + SW_{Environmentalist}\,(TWS_{SLC(Environmentalist)}) + SW_{Others}\,(TWS_{SLC(Others)})$$

Equation 5-1 Measuring ECD

If required, this equation could be further expanded through treating significant stakeholder subsets within the broad stakeholder groupings, in Table 5-1, separately, i.e. having independent designer weightings. Finally, to facilitate the matrix scoring process the non-categorized list of requirements and environmental considerations identified in 'Survey A' were used in developing an ECD category checklist. This checklist (Appendix B) will provide guidance to the LCT on each category when scoring a particular product, and will be further developed throughout the thesis.

Varying factors that could influence the results are discussed in detail in Section 5.4.

5.1.6 Conclusions from PCs Surveys

The surveys achieved their main aims of acquiring a 'body of knowledge' from a range of stakeholder for PCs. The methodology for integrating this 'body of knowledge' into an abridged ECD process has been further developed through a matrix based approach. The approach considers the views of a range of stakeholders and examines MLC options. The next stage involved collection and analysis of information from key internal and external stakeholders in two related industrial case studies.

5.1.7 Background to Industrial Case Studies of PCs

This phase involved collection and analysis of information from key internal and external stakeholders in two related industrial case studies. Details of case studies 1 and 2 are outlined in Table 3-3. This provided qualitative and quantitative field data for the 'body of knowledge' and methodology. The first case study involved identifying and analyzing the major environmental considerations associated with the manufacture of a computer keyboard component. The results from this study were then used in the analysis of the full life cycle of a computer keyboard. The studies involved spending extended periods of time in the collaborating companies and resulted in the construction of a list of important environmental considerations over the life cycle of a keyboard. These considerations resulted in a case study 'body of knowledge'. The studies also resulted in the identification of cost-effective, environmentally beneficial improvements and recommendations for strategies for future product development.

The Company

Alps, a medium sized company based in Millstreet Town, Co. Cork, Ireland, was selected for the two case studies. Alps, a division of the Alps Corporation, has been designing and manufacturing PCs since 1988. In 1993, as a result of a charter, issued by the Alps general manager, an in-house 'Electronic Waste Recycling Group' was formed. This group consisted of representatives from each of the company main divisions: design and development, manufacturing, sales and marketing, workplace/process improvements, distribution and project engineering. These representatives became 'environmental champions' for both Alps and the Alps Corporation. Prior to commencing this research, the author had been the company's environmental champion for design and development. Thus he had assisted the company in developing waste minimization systems, gaining certification to the Environmental Management standard, ISO 14000, and integrating environmental considerations into existing designs (O' Connor *et al.*, 1998d). An ECD checklist was developed by the author, in consultation with internal stakeholders, to provide generic guidance to the company on disassembly, material selection, standardization, emissions, manufacturing and other considerations. Design improvements on existing products included use of snap fits instead of fasteners, selection of materials compatible with recycling, coding for recycling, minimization of parts, and designing for disassembly. The key guidelines from this checklist are included in the ECD category checklist, Appendix B. As a key requirement of ISO 14000 is continual improvement; Alps began examining ways of monitoring the company's environmental performance. The technique selected was environmental performance profiling (EPP) through consulting the stakeholder. It involved use of a matrix technique to identify stakeholders' perceptions of the company's environmental performance (O' Connor *et al.*, 1998d). An EPP study on a number of employees highlighted two significantly 'weak' areas: the company's portfolio of products, and their marketing approach. Focusing predominantly on the company's products, the author subsequently drafted a proposal on the benefits to the company from participating in the case studies. Upon agreement of the proposal Alps assigned a 'Liaison Person' who was also one of the companies environmental champions, Mr. P. Phelan (Technical Services Manager). Having one of the environmental champions as the liaison person was regarded as a prerequisite to ensuring successful ECD. The liaison person was an educated engineer with no environment-related qualifications, but who had specific product and manufacturing knowledge and experience. As McAloone (1998) points out, this background may ensure empathy with the daily routine of the people required in bringing about change. The liaison person's role was to provide a direct link to the company and to provide access to product and supplier information and product samples.

5.1.7.1 Case Studies Approach

Alps required a relatively quick, cost-effective approach, which would address environmental considerations such as energy consumption and disposal, alongside traditional design requirements such as cost and health and safety. The abridged approach developed by Graedel and Allenby (1995) was modified to meet the specific needs of the company. The approach involved drawing boundaries around the stages or processes being analyzed. The key environmental considerations were identified for each stage of the products life cycle through analyzing documentary evidence, product analysis, participant observation, measuring quantitative values, where available, along with the collection of qualitative data through discussions and informal interviews with members of the Alps CFT. Participant observation was particularly useful in reporting on the manufacturing and usage stage of the product. This was supplemented by additional data obtained from suppliers, sub-contractors and other key stakeholders. There are many environmental and non-environmental considerations that are characteristic of a keyboard. However, to make the study practical, within the limited time constraints, it was necessary to limit the range of considerations to those that were determined as important by the key stakeholders. This approach enabled key considerations to be identified and weighted for matrix analysis and scoring. It also enabled additional stakeholder criteria to be added to the ECD category checklist. The iterative ECD approach involved three key stages: 'Data Gathering', 'Data Analysis' and 'Incremental or Radical Improvement', Figure 5-15. The analysis stage included prioritization and reporting of the results with the inclusion of specific stages being flexible. This approach is similar to that adopted by many other companies (Simon *et al.*, 1998). It should be noted that the information used for the keyboard study was obtained at the detailed design stage, after many of the design decisions had been made, and just prior to product tooling.

5.1.7.2 Case Study Tools

The approach used a number of tools including:

- Input-output flow diagrams
- Matrices
- Profiling
- Checklists / Strategies
- Creative thinking tools

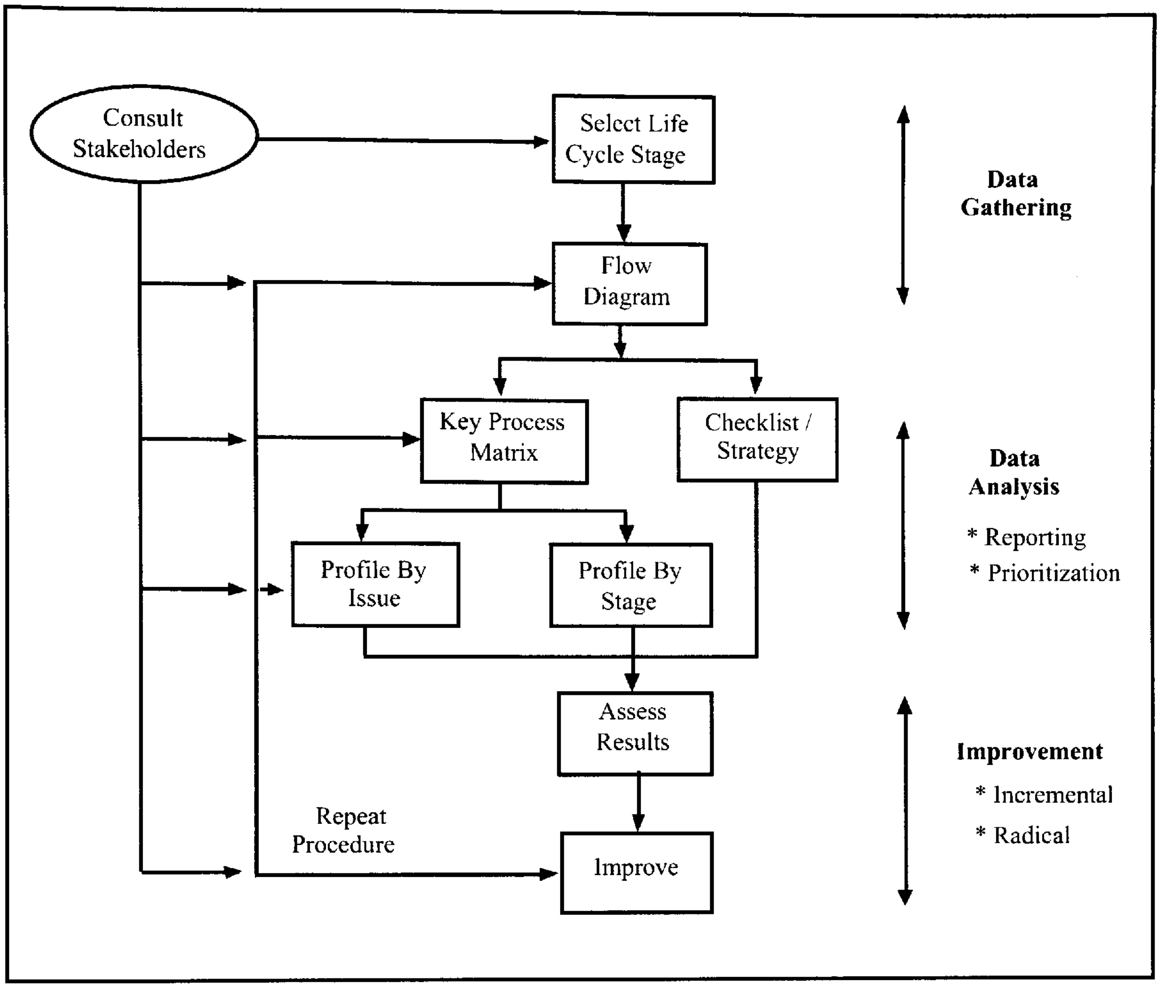

Figure 5-15 Iterative ECD Approach

Input-Output Flow Diagrams

These had a number of functions including:

- To highlight the main resource flows for the component and keyboard at various stages in their respective life cycles.
- To illustrate the typical daily usage transactions and EOL asset management routes for the keyboard.
- To ensure all the key considerations are determined.

For clarity the flow diagrams used the following abbreviations: Energy (E); Heat (H); Noise (N); Storage (St); Transport (T). Rejects refer to packaging, material and component waste.

Matrices

The matrices, which can incorporate both quantitative and qualitative data, were used to assemble the considerations in a format suitable for evaluation. Weightings, and rankings or scores were assigned to key environmental considerations or key processes through a team effort, utilizing the views, knowledge and experiences of both internal and external stakeholders. For the purpose of the case studies the following scales were used to semi-quantify the evaluation.

Table 5-11 Weighting Scale for Case Studies 1 & 2

1	2	3	4	5
Not Important	Low Importance	Medium Importance	High Importance	Very High Importance

Table 5-12 Scoring Scale for Case Studies 1 & 2

0	1	2	3	4
No Concern	Low Concern	Medium Concern	High Concern	Very High Concern

Table 5-13 Ranking Scale for Case Study 1

1	2	3
Best .... Worst		

Using the weighting and scoring system, the worst scenario, i.e. maximum environmental concern, is that a consideration would be rated 'very high importance' and would score 'very high concern' giving a 'Weight.Score' of '20'. The best scenario, i.e., least environmental concern, is a 'Weight.Score' of '0'. Using the weighting and ranking system the worst scenario, i.e. maximum environmental concern, is that a consideration would be rated 'very high importance' while the process would rank 'worst' giving a 'Weight.Rank' of '15'. The best scenario, i.e:, least environmental concern, is a 'Weight.Rank' of '1'. These numbers were used as performance indicators to measure improvements. Clearly the choice of weightings strongly influences the final result and thus should be decided through group consensus.

Profiling

The profiles or target plots helped highlight the considerations and stages of greatest concern and provided a means of setting precise targets for improvement.

Checklists / Strategies

These tailor-made tools were used to assist when defining environmental priorities and devising design rules. They were also used to support other decision-making actions at various stages of the keyboards life cycle. The ECD category checklist was updated to reflect the views of a wider range of internal and external stakeholders. ECD strategies considered included usage eco-efficiency, design for disassembly, and life extension.

Creative Thinking Tools

These were used to support idea generation at the improvement stage through integrating environmental mind-sets into the traditional creative tools such as the 'random word' technique. The 'random word' technique was used to support idea generation at the improvement stage. It is one of several lateral-thinking techniques devised by De Bono (1981). This technique forces the association of a deliberately random word with the subject in order to promote thinking outside of the traditional track of ideas. It can be used to provide fresh or additional ideas on any occasion.

5.1.7.3 Scope of Case Studies 1 and 2

The life cycle stages that Alps was most interested in analyzing were manufacture, distribution, usage, service, and EOL asset management. Figure 5-16 relates the studies to the keyboard life cycle.

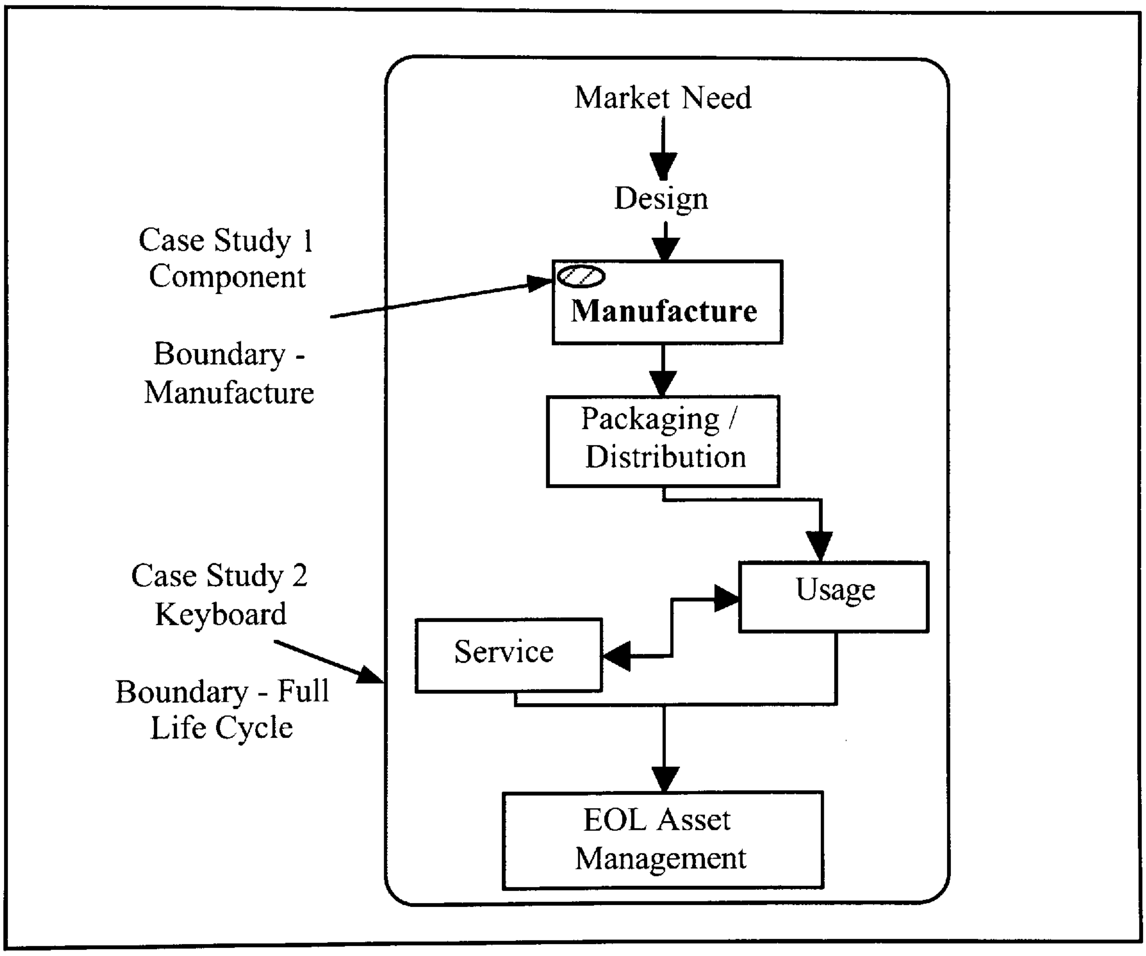

Figure 5-16 Simplified Keyboard Life Cycle

5.1.8 Case Study 1 – Computer Component

The aim of the case study was to systematically analyze the major environmental considerations associated with the manufacture of a computer keyboard component. The data collection was carried out over a period of 2 days based on site in Alps. The components are produced in a variety of materials and colors, with different finishing processes for different applications. Due to a confidentiality agreement it is not possible to disclose the exact nature of the component, manufacturing processes, or key environmental considerations. Initial results from the study are published in O' Connor *et al.* (1998b) and O' Connor *et al.* (1998c).

5.1.8.1 Data Collection

A boundary was drawn around the manufacturing stages of the component, restricting the study from the actual receipt at the factory of the component raw material, to the passing of the finished assembly to packaging and storage. The prominent manufacturing stages along with their major inputs and outputs are represented through a flow diagram in Figure 5-17.

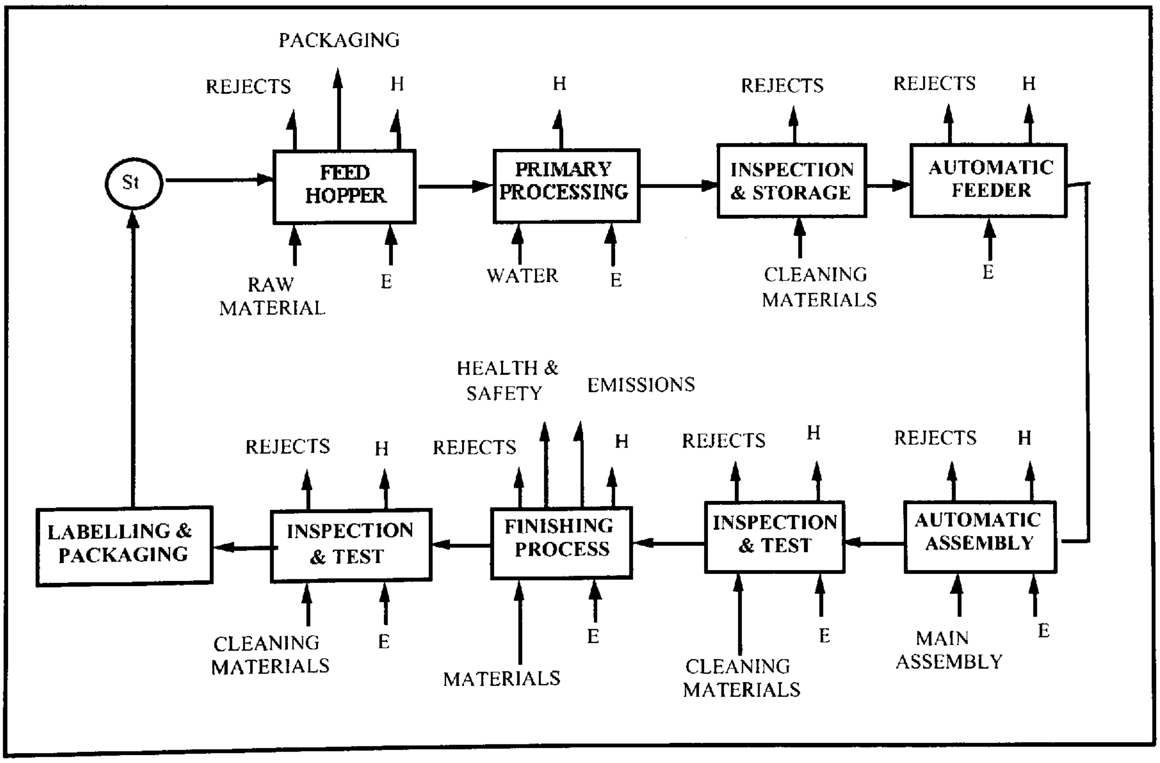

Figure 5-17 Simplified Manufacturing Cycle for Computer Component

Generally, these stages would be similar for most manufacturers with the main exception being the choice of finishing process. Three finishing processes, FP1, FP2, and FP3 respectively were available to Alps. There is a variety of reasons; including cost, aesthetics and reliability; as to why different finishing processes are specified by the design and marketing teams. Rarely, if any, do environmental reasons play a part in these decisions.

Initially, the manufacturing process was examined using two approaches; reject component disposal and process energy consumption. These were based on Van der Horst and Zweers (1994) 'closing materials cycles' and 'energy indicators' approaches respectively which were reviewed in Chapter Two. The environmental impact of components other than the one being analyzed were noted, but ignored in the assessment.

Reject Component Disposal

Examination of the disposal of reject components indicated that up until the finishing process they were all treated as uncontaminated, regardless of the material. This enabled them to be recycled within the manufacturing process. The rejects from the three available finishing processes, FP1, FP2, and FP3 respectively, were contaminated to varying degrees and thus needed to be examined further.

Process Energy Consumption

The energy consumed at each of the main manufacturing stages was calculated, with the high energy consuming stages being primary processing, automatic assembly and the finishing process. The energy consumed in the primary processing and automatic assembly stages was similar for all of the different components. Significant energy variations were noted on the three available finishing processes. FP2 and FP3 consumed approximately twice as much energy as FP1, therefore it was decided to concentrate on their environmental impacts.

5.1.8.2 Data Analysis

A detailed matrix evaluation comparing the environmental impact of the three finishing processes was completed. The environmental matrix incorporated energy values, based on quantitative data and the qualitative values for all the other considerations: health and safety, emissions and disposal, Table 5-14. Each issue was firstly weighted in terms of its relative importance. A score was then assigned to each technique based on how it performed against each of the respective environmental considerations. FP1 scored lowest (minimum environmental impact) followed by FP2 with FP3 scoring highest (maximum environmental impact). Whilst FP1 consumes the least amount of energy the other two consume equivalent amounts.

Table 5-14 Matrix Analysis - Environmental Manufacturing Considerations (Computer Component)

Environmental Manufacturing Considerations	Weight	FP1		FP2		FP3	
		Score	WS [a]	Score	WS	Score	WS
Energy	3	1	3	3	9	3	9
Health & Safety	4	1	4	2	6	4	16
Emissions	3	3	9	1	3	4	12
Disposal Item A[19]	2	0	0	0	0	4	8
Disposal Item B	2	1	2	3	6	3	6
Disposal Item C	2	0	0	4	8	1	2
Total Weight.Score (TWS) [b]		18		34		53	

[a] WS is the weighting by the respective score for the process

[b] TWS represents the sum of the individual 'WS' for each of the processes

[19] Due to a confidentiality agreement, it is not possible to disclose the exact nature of these environmental considerations.

The results were then profiled to highlight the most environmentally conscious process, along with considerations to be targeted for improvement, Figure 5-18. The two considerations of greatest concern for the least efficient option, FP3 were health & safety and emissions.

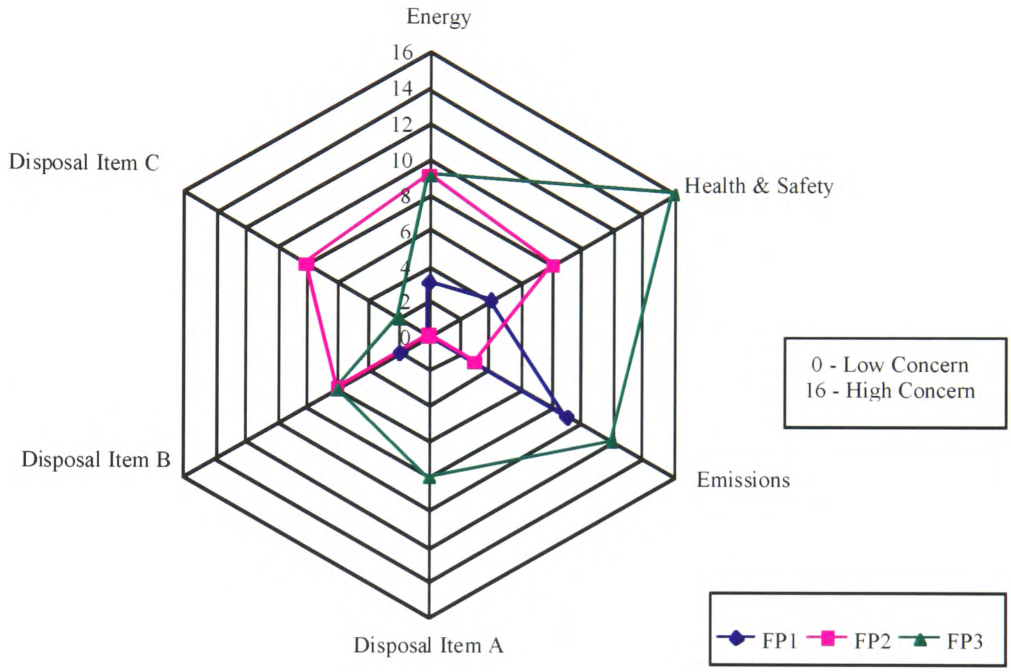

Figure 5-18 Environmental Manufacturing Considerations Profiles (Comp. Component)

Other Influencing Factors

Along with environmental considerations, other criteria influence the choice of finishing process equipment. A detailed matrix evaluation comparing set-up time, costs, reliability of finish, human factors during usage, material selection options and environmental manufacturing considerations was completed, Table 5-15. Using the ranking system, FP1 was again found to be the best long-term option, although the margins of difference between the processes was much less than in the previous matrix analysis. The analysis does not reflect the fact that FP1 is the only system that cannot be used if multi color components are required, as is the case with some products. The use of multi colors is a decision where the environmental implications may not be apparent.

Table 5-15 Matrix Analysis – Key Influencing Factors (Computer Component)

Influencing Factors	Weight	FP1		FP2		FP3	
		Rank	WR [a]	Rank	WR	Rank	WR
Material Options	2	2	4	3	6	1	2
Finish Reliability (Usage)	3	2	6	1	3	3	9
Human Factors (Usage)	4	3	12	1	4	2	8
Environmental Issues	4	1	4	2	8	3	12
Color Options (Usage)	4	2	8	2	8	1	4
Equipment Cost	2	3	6	1	2	2	4
Equipment Set-up Cost	4	1	4	3	12	2	8
Equipment Set-up Time	4	1	4	2	8	2	8
Total Weight.Rank (TWR) [b]		48		51		55	

[a] WR is the weighting by the respective rank for the process

[b] TWR represents the sum of the individual WR for each of the processes

The results were then profiled to highlight areas that could be targeted for improvement, Figure 5-19. The two considerations of greatest concern for the least efficient option, FP3 were environmental manufacturing considerations, and reliability of finish during component usage.

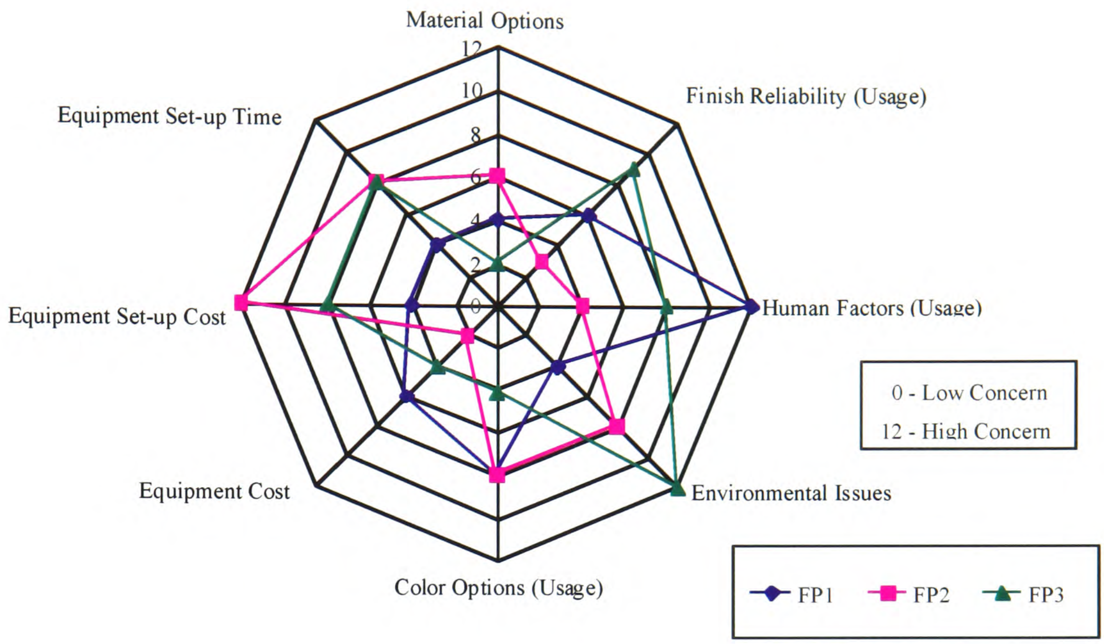

Figure 5-19 Profile of Key Influencing Factors (Computer Component)

5.1.8.3 Improvement

The design and marketing teams are now aware that the use of multi colors has an adverse affect on the environment, in terms of health and safety, emissions and disposal. The results from the study were used to improve the components environmental performance during manufacture. Improvements focused on FP3 and the key considerations of concern highlighted: health and safety, emissions, disposal of item 'A', and reliability of finish. The direct replacement of FP3 with either FP1 or FP2 was not possible in the short-term as customers specifically requested the color options. Also, through consulting relevant stakeholders it was identified that the market for multi colored components was increasing every year. An investigation into the possibility of upgrading, and improving the efficiency, of FP3 was completed. Working closely with the equipment supplier and manufacturer, it was established that upgrading the equipment for FP3 would result in a more environmentally friendly system. An assessment of the upgrading implications was undertaken using the matrix technique. This confirmed that the upgraded system would result in a reduction in air pollution, rejects and health and safety concerns, along with improved reliability through an increase in consistency. Long-term improvements could involve a shift in market requirements away from multi colored components, or, innovative design solutions, such as environmentally friendly finishing process equipment for multi colored applications. The company instigated a long-term investigation into the availability and efficiency of alternative finishing equipment to color the components.

5.1.8.4 Summary of Case Study 1

The key result was that a design decision was at the root of the main environmental impact; selection of colors for components, pre-determined through customer requirements, resulted in an environmentally unfriendly finishing process. Under these constraints, the modified approach adopted provided a quick, yet effective method of analyzing the environmental performance of the component during manufacture. It also provided a platform for its improvement. The method resulted in a comparison of existing finishing processes, with FP1 added to the ECD category checklist as the most environmental friendly option. The environmental manufacturing considerations and other influencing factors form part of the case study 'body of knowledge' included in the ECD category checklist.

5.1.9 Case Study 2 – Computer Keyboard

The aim of the case study was to systematically analyze the major environmental considerations associated with the full life cycle of the 'Hi-Rise' computer keyboard, from market definition through to EOL. This would provide Alps with a quick overview of the products environmental performance at the detail design stage. The data gathering was carried out over a period of 2 weeks; one week based on site in Alps, and the remaining time based at stakeholder sites. Preliminary results from the study are published in O' Connor *et al.* (1998a) and O' Connor *et al.* (1998c).

'Hi-Rise' Computer Keyboard

The computer keyboard, named the 'Hi-Rise' due to its distinctive and unique profile, was developed through the Alps CE system using a CFT. It provides a single answer to all banking and financial needs, Figure 5-20. The design consists of a number of integrated key elements, with in-built security features, and supported with an utility software tool for programming the devices:

- multi-functional keyboard with enhanced numeric pad, unique in-line magnetic and smart card reader[20]
- cheque reader and additional smart card reader (optional)
- touch-pad and up to 20 additional hot keys (optional)
- operator Liquid Crystal Display (LCD) (optional)

Figure 5-20 'Hi-Rise' Computer Keyboard (Courtesy of Alps Electric)

[20] This is the main keyboard section, consisting of housings, keycaps, switch-frame and other components.

The combination of these key elements satisfies the top functional level requirements of cost and market needs.

Market Pull or 'Eco-Push'

The Hi-Rise solution resulted from extensive research into the needs of business users. The case of the Hi-Rise is unique, in that the market innovation team had identified that environmental criteria formed part of these needs. Of the 15 key considerations identified by a range of users, 7 could be considered as environmental criteria (O' Connor *et al.*, 1998a). These environmental criteria (Table 5-16) indicate that business users are undertaking some form of 'eco-push' in a traditional market pull product. In developing the Hi-Rise, Alps inadvertently took an approach similar to the 'environmental marketing' method outlined by Van der Horst and Zweers (1994), which was reviewed in Chapter Two.

Table 5-16 Key Environmental Criteria (Hi-Rise Computer Keyboard)

Criteria	Possible Environmental Benefit
Small keyboard footprint	Reduced use of materials
Future proof	Reduced resource consumption
Long-life	Reduced resource consumption
Upgradeable	Reduced resource consumption
Real need to fulfill	Consumer satisfaction
Reduce resource consumption in office	Reduced usage resource consumption
Some sustainable features	Reduced resource consumption

5.1.9.1 Data Collection

The main keyboard section, with the exception of the in-line reader, is similar to other standard Alps desktop keyboards designed for home and office use. It was possible to collect data on this element through examining current keyboard life cycles. Criteria from the 'Blue Angel' label and the internal ECD checklist had previously been applied to these keyboards, so many of the recommended design guidelines for standardization, use of recyclable plastics, and identification were already incorporated in the Hi-Rise[21]. Alps had no control over the design and manufacture of the bought-in elements, which were key to the market success of the keyboard. Due to time constraints, it was only possible to examine information that was readily available. Therefore, the study did not focus on the processes employed by suppliers to manufacture, and deliver, the various components that were incorporated in the product. The design and material and component selection processes were examined initially. A boundary was then drawn around the manufacturing stages of the product, restricting the study from the actual delivery at the manufacturing line of the raw material and components, to the packaging of the finished assembly. FP1 was selected for this product based on the results of the previous case study. From this, the study was expanded to include the other key life cycle stages and their respective stakeholders.

5.1.9.2 Data Analysis

The Alps product design, and material and component selection processes were reviewed, highlighting limitations, and developing additional guidelines for the ECD category checklist. A matrix evaluation was undertaken of the manufacturing and usage stages against the key environmental concerns. The results were profiled and used as performance indicators to measure subsequent environmental improvements to the keyboard. The study involved identifying the key environmental considerations of various stakeholders in the life cycle of a standard desktop keyboard from molding, through distribution and service, to EOL asset management. Where possible, these stages and considerations were reviewed in terms of the Hi-Rise. The key environmental considerations were then used in compiling the case study 'body of knowledge' through the ECD category checklist.

[21] The Blue Angel is an environmental label awarded by the Ministry of the Environment in Germany.

Product Design Process

The product design process used by Alps is similar to the model outlined in Figure 1-1. Alps aspires to a CE system, using design reviews at critical points in the process, to ensure that the project is running correctly. Members of the CFT were interviewed on an informal basis. The aim of this section was to identify where environmental considerations were currently being integrated into the design process, limitations in the current approach, while suggesting improvements (Table 5-17).

Table 5-17 Limitations of the Hi-Rise Design Process

Issue	Improvement Suggestion
The CFT involved internal stakeholders. The only exception being the market innovation team.	Involvement of external stakeholders such as sub-contractors, service experts and EOL asset managers at predetermined stages of the design process.
ECD was implemented at the detailed design stage and based on the Blue Angel criteria and internal ECD checklist. Alps also took an approach similar to the 'environmental marketing' method.	Introduce ECD as early as possible in design process (the detail design stage is too late). Use other ECD techniques also.
Prototypes were developed without any consideration of environmental impact and were not recycled.	Use 3D concept images or animation for initial market testing. Where possible use recyclable materials (i.e. wood, paper).

Materials and Component Selection

Alps use a list of approved suppliers for the materials and components used in its products. When adding a supplier to the 'Approved Supplier List', the three key issues are cost, engineering specification, and availability. Environmental considerations are not deemed important unless they are performance related, i.e. result in reduced energy consumption. The main plastic and rubber materials and the metal plate used in the Hi-Rise are recyclable and conform to Blue Angel criteria. The keyboard encompasses a wide variety of supplied components, i.e. smart card readers, which have not been evaluated in terms of environmental performance. Excluding the electronic components (i.e. resistors, capacitors etc.) attached to the main printed circuit board (PCB), the keyboard contains over 350 separate items. This is a high concern in terms of resource consumption, assembly and disassembly. Some limitations in the current approach and suggested improvements are given in Table 5-18.

Table 5-18 Limitations of the Hi-Rise Material and Component Selection Process

Issue	Improvement Suggestion
Materials and components are selected without any consideration of environmental performance.	Inclusion of environmental considerations in formal approval process for materials and components and their suppliers, i.e. use of a template as given in Table 5-19.
	Ensure suppliers have an environmental policy and have, or are in the process of setting up, an active ECD system.
Over 350 items are used in product, including 5 different plastic materials, some of which have very similar properties.	Minimization through use of snap fits and integration of components.
	Standardization of materials used in products (Material selection tools, that include environmental criteria, could be implemented, i.e., tool developed by Chen, 1995).

Table 5-19 Sample Material and Component Selection Template

Key Criteria	Materials/Components/Suppliers		
	Option A	Option B	Option C
Cost			
Specification			
Availability			
Environmental Considerations			
Others (Localization, Policies, etc.)			

Manufacture

The proposed stages in manufacture of the Hi-Rise keyboard were drafted initially in a flow diagram format, highlighting the major inputs and outputs. A simplified flow diagram, Figure 5-21, shows the stages that were found to be of greatest concern along with some link stages.

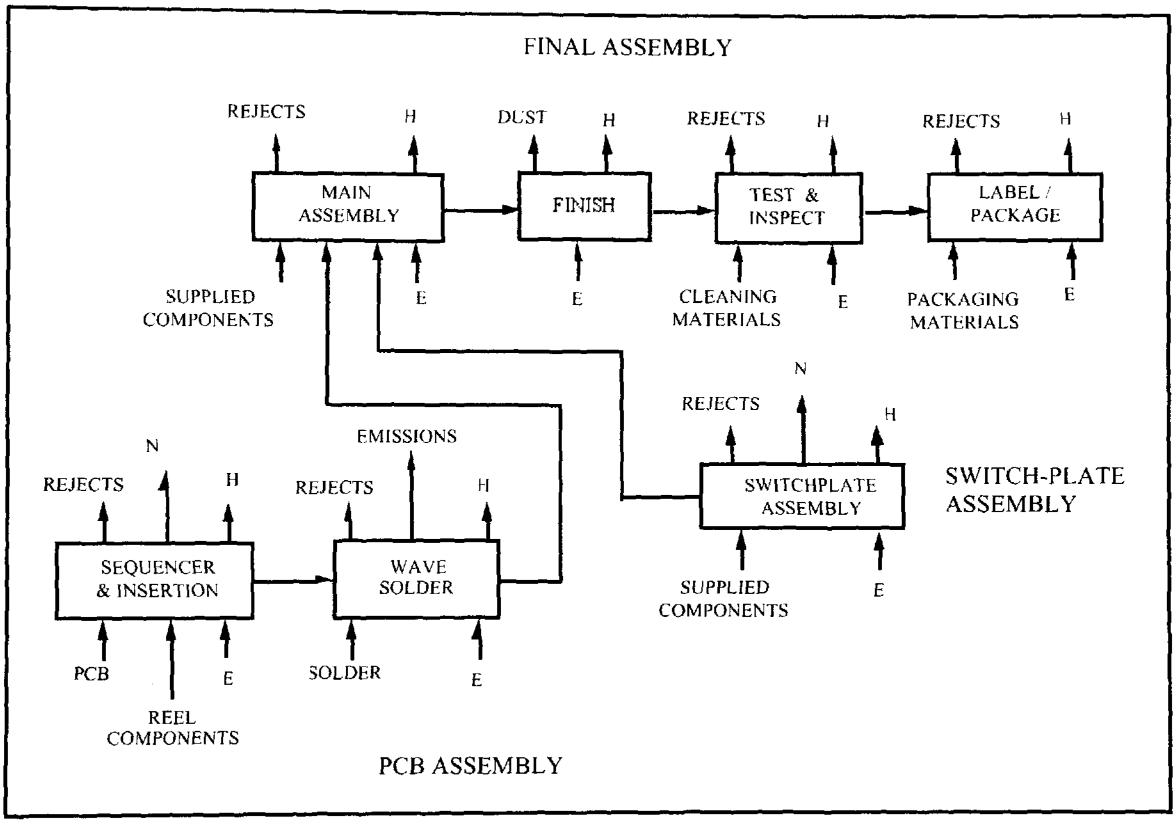

Figure 5-21 Simplified Computer Keyboard Manufacture (Hi-Rise)

A matrix evaluation was undertaken of the three stages of most concern against their respective environmental concerns, Table 5-20. The three stages are illustrated in Figure 5-22, Figure 5-23 and Figure 5-24 respectively. The results were then profiled by environmental issue and by stage, see Figure 5-25 and Figure 5-26.

Figure 5-22 Sequencer (Courtesy of Alps Electric)

Table 5-20 Matrix Analysis – Manufacturing Considerations (Hi-Rise)

Environmental Considerations	Weight	Sequencer Score	Sequencer WS	Insertion Score	Insertion WS	Wave Soldering Score	Wave Soldering WS	TWS
Energy	4	2	8	3	12	4	16	36
Health & Safety	5	1	5	2	10	3	15	30
Emissions	4	0	0	0	0	3	12	12
Reject Disposal	4	2	8	2	8	4	16	32
Package Disposal	3	2	6	0	0	0	0	6
Human Factors	4	1	4	3	12	1	4	20
Resource Consumption	3	0	0	0	0	1	3	3
Total Weighted Score (TWS)			31		42		66	139

Figure 5-23 Insertion Machine (Courtesy of Alps Electric)

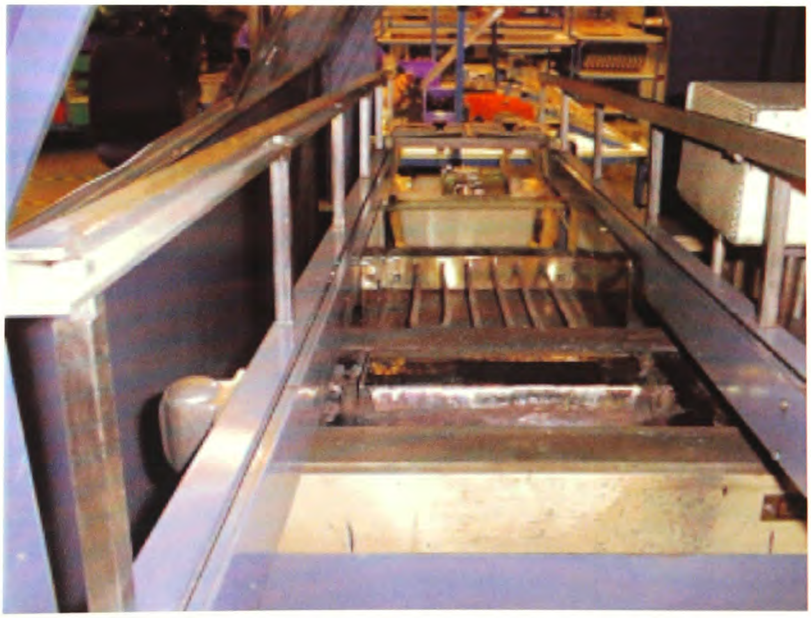

Figure 5-24 Wave Soldering Machine (Courtesy of Alps Electric)

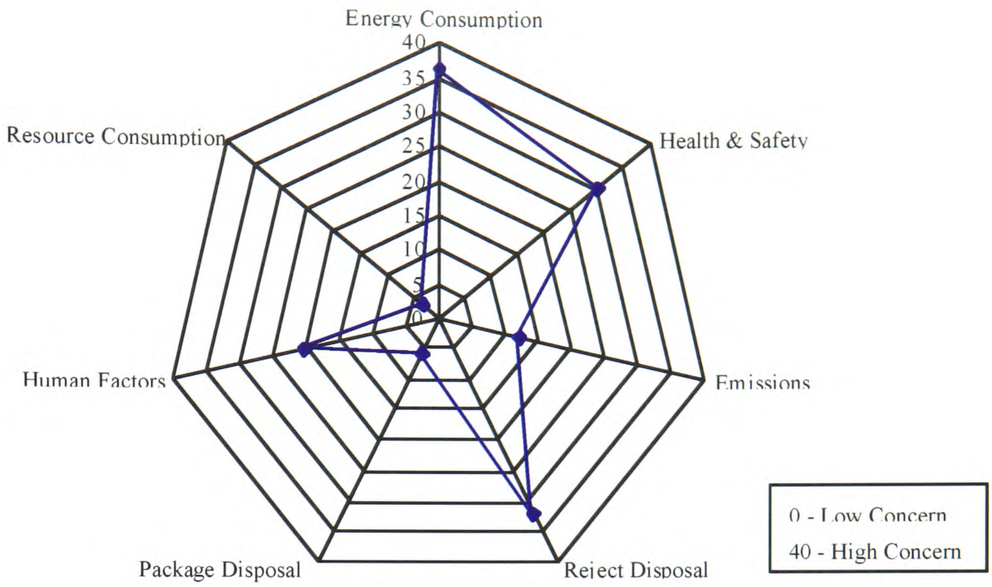

Figure 5-25 Key Manufacturing Considerations Profile (Hi-Rise)

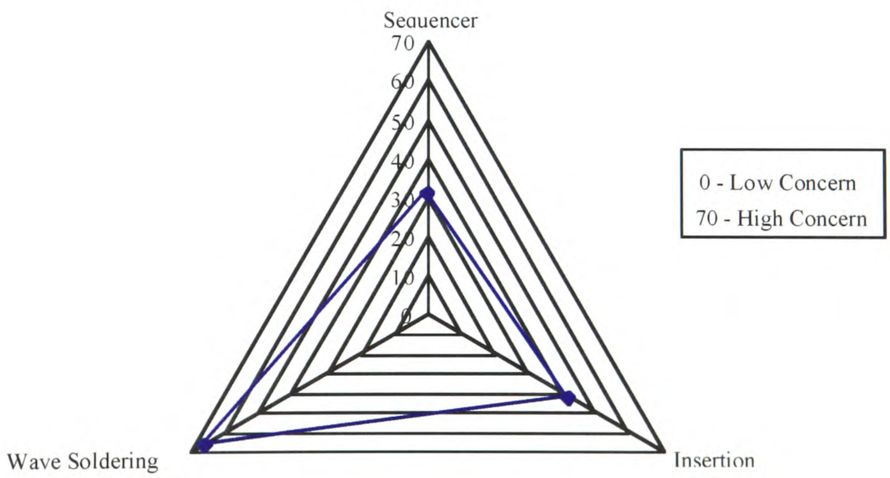

Figure 5-26 Key Manufacturing Stages Profile (Hi-Rise)

Review of Manufacturing Stage

The three environmental considerations of greatest concern were energy, reject disposal and health & safety respectively, Figure 5-25. The three stages of most concern are all related to the preparation and attachment of the electronic components to the PCB. Soldering performed the worst (Figure 5-26) with a high score for each of these three considerations. Thus, a key objective is to provide alternative methods of preparing and attaching the electronic components. One such study at an advanced stage, is the development of a fabrication technique for printing circuit board designs onto suitable substrates. Conductive lithographic films have been successfully demonstrated in a telephone handset (Ramsey, Evans and Harrison, 1997). Finally, the assembly, set-up costs and other manufacturing issues were based on existing keyboards and were ignored in this assessment.

Usage Stage

The keyboard offers a range of solutions through the optional discrete elements. It is designed to be future proof for a minimum of 7-8 years giving it a relatively long life cycle[22]. After 3-4 years Alps would upgrade the keyboard[23]. This process would include replacement of the cheque reader and/or other discrete elements. A specific customer application, which did not involve use of the smart card readers, was selected for analyzing the typical usage transactions. A flow diagram of the typical daily usage transactions was drafted, Figure 5-27. The operator spends the majority of the time in an average day completing miscellaneous tasks, with only 37.5% of the time given to interfacing with the keyboard, Table 5-21.

Table 5-21 % Breakdown of Operator Transactions (Hi-Rise)

Transaction	% Of Day
Graphic/Data entry	25
Magnetic card/Cheque reader	12.5
Miscellaneous tasks	62.5

[22] The average life of a personal computer is 3-5 years (Kostecki, 1998).

[23] This is the average life of competitor products.

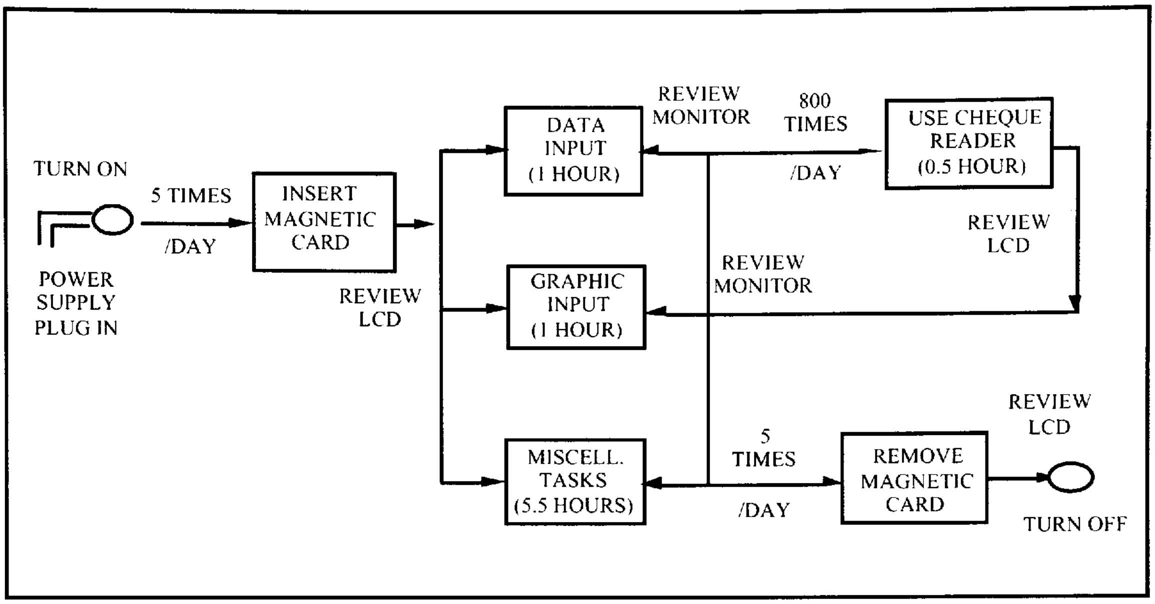

Figure 5-27 Typical Daily Usage Transactions (Hi-Rise)

A matrix analysis was completed for the product, based on this specific application, Table 5-22.

Table 5-22 Matrix Analysis – Usage (Hi-Rise)

No	Environmental Considerations	Weight	Score	Weight.Score
1	Product Energy	4	1	4
2	Quality & Reliability	5	1	5
3	Health & Safety	5	1	5
4	Human Factors	4	2	8
5	Physical Properties	3	1	3
6	Features/Functionality	3	1	3
7	Sustainable	4	3	12
8	Product Cost	2	2	4
9	Aesthetics	2	2	4
10	Disposal Issues (Battery)	3	3	9
11	Usage Resource Consumption	4	1	4
Total Weighted Score (TWS)				61

The environmental considerations were identified and weighted by reviewing the market needs and key design criteria, studying the usage application, and through informal discussions with the market innovator, user and designers. The results were then profiled, Figure 5-28.

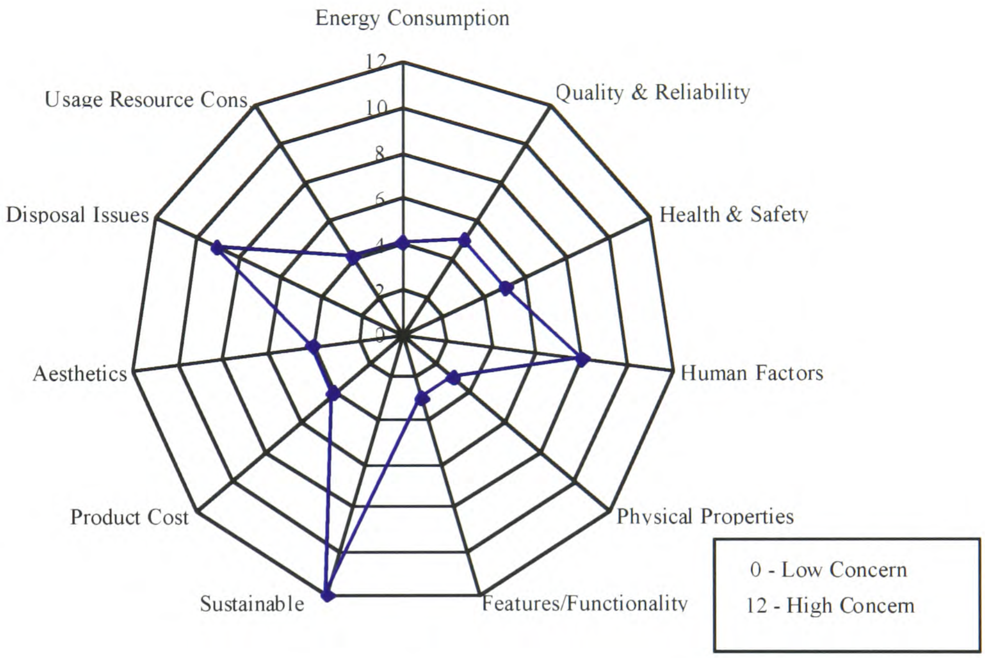

Figure 5-28 Usage Considerations Profile (Hi-Rise)

Review of Usage Stage

One concern highlighted was the potential need of a battery to power the cheque reader, and its subsequent disposal at EOL. Alps will either provide a take-back system for them or recommend the best disposal route to their customers. 'Health & safety' and 'human factors' are considered by Alps to be of low concern as the keyboard complies with applicable international standards and the operator will spend just slightly over a third of the day interacting with the keyboard. Guidance and instructions will be provided to ensure that the workstation is designed to incorporate the product. 'Sustainable' features were included in the usage analysis and rated as a high concern[24]. The keyboard aims to have an extended product life through attempting to be 'future proof'. It also attempts to satisfy real market needs but in doing so incorporates a wide variety of components that have not taken sustainability criteria into consideration. Through building in a service contract, Alps has provided an eco-efficient product oriented service. The customer can be trained in the optimum way to use the product and have their products serviced and upgraded on a regular basis. By offering the products on a rental or lease basis, Alps could offer their customers an eco-efficient use oriented service. A multi-user sharing option is not possible due to the level of security required for these business applications. Rental or lease would also allow the company to maintain control of the product throughout its life cycle, and enable take-back at EOL for reuse, remanufacture, or recycling. Although the keyboard focuses on the real needs of business users it will not be possible to offer an eco-efficient need oriented service due to security reasons.

Plastic Molding Sub-Contractor

The main plastic components of a standard keyboard, and the Hi-Rise, are injection molded by a sub-contractor. Some sub-contractor personnel were interviewed to ascertain environmental considerations. Some of the issues not previously taken into account by the CFT are outlined in Table 5-23 along with the possible environmental improvements. The additional criteria were added to the ECD category checklist (Appendix B).

[24] Product features that consider the needs of the present without compromising the ability of future generations can be termed 'Sustainable'.

Table 5-23 Molding: Some Additional Criteria

	Considerations	Possible Environmental Improvement
1	Where possible specify regrind (30%).	Reduced resource consumption through specifying regrind for the bottom housings or internal components. May require a change in perception of regrind by the industry and its customers.
2	Correct wall thickness for regrind.	Reduced resource consumption through reuse of waste material.
3	Use mold flow analysis.	Reduced environmental impact at manufacture through minimization of tool trials.
		Reduced rejects and waste.
4	Ensure accurate forecasting of sales volume.	Reduced resource consumption due to production of required volume. Over production shortens the tool life and results in additional maintenance. Raw materials are purchased based on forecasts so any additional material purchased requires storage under controlled conditions thus resulting in further environmental impact.
5	Order size for distribution.	Reduced environmental impact through having full loads on delivery.
6	Reusable packaging for transporting finished goods.	Extended life spans and reduced resource consumption through reuse.

Distribution (Include. Storage and Packaging)

One day's stock is normally kept in the production plant with the remaining inventory kept at a nearby warehouse. Transport to customers is sub-contracted to delivery companies and is by land, and air or sea, depending on the delivery deadlines. The made-to-order Hi-Rise keyboards are packaged in a plastic bag, with instruction manual, within a plain single box before shipping in a 5-pack multi-box. They do not contain any retail packaging so the 'Green Point' system will not be required[25]. Where possible, Alps will directly reuse the packaging

[25] The 'Green Point' is a packaging logo that indicates to the consumer that the material is recyclable.

but this will depend on customer requirements. Some of the key criteria identified through discussions with the relevant stakeholders are presented in Table 5-24, along with some possible improvements. All of the additional criteria were added to the ECD category checklist.

Table 5-24 Distribution: Some Additional Criteria

	Considerations	Possible Environmental Improvement
1	Storage time of stock and finished goods, goods made-to-order and accurate forecasting.	Reduced storage time results in reduced environmental impact (The Hi-Rise is made-to-order).
2	Order size for distribution and use of fixed delivery runs.	Reduced environmental impact through having full delivery loads.
3	Packaging size, shape, method, ease of stacking and storing.	Reduced environmental impact through efficient storage and distribution.
4	Reduction of volume of materials such as polystyrene.	Reduced resource consumption.

Service

As the keyboard is being sold to businesses rather than individual users Alps can provide a direct two-way, service and upgrade relationship. The initial cost of the product makes it viable to repair and upgrade, rather than dispose[26]. Some of the concerns highlighted by service personnel from their experiences with standard keyboards that were not previously considered by the CFT are given in Table 5-25. All of these additional criteria were added to the ECD category checklist.

[26] The cost of a unit can vary from £250 to £500 depending on the configuration.

Table 5-25 Service: Some Additional Criteria

	Considerations	Possible Environmental Improvement
1	Increase visibility, accessibility and location of components.	Improved ease of disassembly and repair and reduction of waste (On a trial run the Hi-Rise touch-pad was especially difficult to access and reassemble).
2	Consider ease of de-soldering, re-soldering along with removal and replacement of surface mount components.	Improved ease of disassembly and repair and reduction of waste.
3	Use clips instead of glue (for cable attachment).	
4	Standardization of components and test equipment (manufacturer, retailer and service center).	
5	Reduce component weight.	Improved ease and efficiency of disassembly and repair (These are issues that should be considered at the early design stage).
6	Reduce time taken to clean and service product.	
7	Availability of failure details and failure history.	Reduced time taken to establish cause of failure thus service efficiency is increased.
8	Relate product warranty to date of sale rather than date of manufacture.	Increase in number of products to be serviced within the warranty agreement. (Otherwise shredding for safe disposal may be the most cost-effective option).
9	Consider issues such as type of screw insert, wall thickness of threaded hole and type of thread.	Increase in number of times that a product can be assembled and disassembled.

EOL Asset Management

Impending legislation makes it imperative that businesses put a take-back system in place for products that have reached their EOL. Through consultation with one EOL asset management company, namely Au Industries Ltd. (AuI), seven main strategies, or routes were identified for EOL electromechanical products. These are: reuse, service, remanufacture, recycle (through disassembly), recycle (through shredding), heat recovery (through incineration) and disposal. Of these strategies, four main ones were identified for standard keyboards after initial collection, storage and detrashing[27]. These are:

- Product reuse (including inspect, test, service, rebadge[28] and resale)
- Material recycling, and component recovery and reuse through disassembly and sorting
- Material recycling through volume reduction, shredding and separation techniques
- Disposal

AuI also suggested that EOL asset management recovery for reuse could take place at three main levels for computer keyboards. These are product, module/sub-assembly (SA)/ component and material.

The Alps standard keyboards had previously being designed for disassembly and recycling using the Blue Angel criteria and internal ECD checklist. Despite this design work, disassembly was deemed neither cost effective or viable for AuI. The most feasible route for keyboards, which could not be reused, was shredding for indirect recycling or safe disposal. Some of the generic considerations highlighted are given in Table 5-26. All of these additional criteria were added to the ECD category checklist.

[27] 'Detrashing' is a term used by EOL asset management companies when products are sorted.

[28] 'Rebadge' is a term used by EOL asset management companies when products are given a new product label.

Table 5-26 EOL Asset Management: Some Additional Criteria

	Considerations	Possible Environmental Improvement
1	Instructions for ease of disassembly – Disassembly Manual.	Improved EOL asset recovery. It is important to work closely with the asset management company to ensure viability. (Security and confidentiality may be of concern to the manufacturer).
2	Supply parts, material & component lists and, where possible, design specifications.	
3	Supply testing details.	
4	Closed loop co-operation between manufacturers, users and suppliers.	Reduced resource consumption and extended lives through secondary markets - manufacturers buy back products; suppliers buy back components; molders buy back materials.
5	Brand name issues for white box goods.	Products life extension through allowing the EOL asset managers to re-brand products and resell them into secondary markets (This has implications for the reputation and liability of the manufacturer.)
6	Quick removal labeling, i.e. labeling that can be removed by grinding or covered over for 'white box goods' branding (rebadging).	Improved EOL asset recovery.
7	Ease of separating and cleaning components and products.	
8	Material selection to include consideration of properties for EOL recovery, i.e. ease of contamination.	Improved EOL asset recovery through use of efficient techniques to separate materials, i.e. density separation.
9	To choose the EOL route consider a range of options, i.e. reuse, recycling, disposal, etc.	Improved EOL asset recovery through selection of the optimum route for the product, i.e. computer keyboards, which could not be reused, could be shredded for indirect recycling or safe disposal.

EOL Asset Management of Hi-Rise

The preferred route for the Hi-Rise is product reuse, although due to the specific nature of the application, and advancements in technology, this may not be possible after the intended life of 7-8 years. A disassembly analysis (Table 5-27) was carried out to estimate the time required, identify design weaknesses, and to suggest possible design improvements (Table 5-28). With one exception, all of the Alps manufacturing stages are reversible. One process involves the permanent removal of material from the support plate.

Table 5-27 Disassembly Analysis (Hi-Rise)

Item	Item(s) Attached To	Mechanical Connection	Electrical Connection	Tools Required
Top Housing	Bottom Housing	Screws (4) and clips	No	Philips-Head Screwdriver
Bottom Housing	Top Housing		Yes	
Security Lid	Bottom Housing	Screws (2)	No	Special Tool
Cheque Reader (Include. Battery)	Top Housing	Clips	Yes	Slotted-head Screwdriver
Smart Card Reader	Top Housing	No	Yes	No
Magnetic Card Reader	Bottom Housing	Screws (2)	Yes	Philips-Head Screwdriver
Touch-pad	Metal Plate	Clips	Yes	Slotted-head Screwdriver
Key Switch Housings (103)	Metal Plate	Clips	No	
Rubber Domes (103)	Key Switch Housings	No	(Contact on deflection)	No
Keycaps (103)	Key Switch Housings	Clips	No	Keycap disassembly tool
Optional Key Covers (23)	Key Switch Housings	Clips	No	Keycap disassembly tool
LCD	Top Housing	Clips	Yes	Slotted-head Screwdriver
Connection Lead	Bottom Housing	Clips	Yes	No
PCB	Bottom Housing	Screws (5)	Yes	Philips-Head Screwdriver
Flex-Membrane	Metal Plate	No	(Contact on deflection)	No
Plate	Bottom Housing	No	(Earth)	No

Table 5-28 Design for Disassembly Limitations (Hi-Rise)

Issue	Improvement Suggestion
Time taken to disassemble main elements of keyboard was 14 minutes (Removal of the key switches took the longest period).	Reduced number of components: - One switch-frame incorporating all keys and integrated to top housing - Rows of keycaps integrated - Rubber domes integrated onto one sheet - Reduced number of screws
Clips for cheque reader and magnetic card reader were difficult to open without damaging housings.	Improved clip design considering disassembly as well as assembly.
Screws for security lid (to access interface for secure electronic transactions) require a special tool to remove.	EOL asset manager to be provided with tool for EOL recovery.

Detailed consideration of the EOL value of the product and its components showed that there is potential value, if a secondary market can be established. Some of the EOL routes may involve indirect recycling and reuse.

Table 5-29 Potential EOL Asset Management of Key Hi-Rise Elements

No.	Part Name	Route	Potential Value
1	Top, Bottom & Key Switch Housings, Keycaps & Key Covers	Recycling	Yes
2	Cheque Reader	Reuse	Yes
3	Battery	Controlled Disposal	No
4	Smart Card Reader	Reuse	Yes
5	Magnetic Card Reader	Reuse	Yes
6	Touch-pad	Reuse	Yes
7	Rubber Domes	Recycling	Yes
8	LCD	Reuse	Yes
9	Connection Lead	Recycling	Yes
10	PCB	Precious Metal Recovery	Yes
11	Flex-Membrane	Recycling	Yes
12	Plate	Recycling	Yes

Review of Molding, Distribution, Service and EOL Asset Management

These sections clearly highlighted the importance of consulting external stakeholders. Through reviewing the existing life cycle route for the standard keyboard, and relating it to the Hi-Rise, many additional environmental criteria were added to the ECD category checklist. Numerous other environmental impacts, which occur at these stages, were largely ignored in this assessment. These included energy consumption, emissions and human factors. The stakeholders were made aware that impacts at each stage of the products life cycle affect the products overall environmental profile. In many situations the stakeholders were reducing their companies environmental impact for other reasons, such as cost and legislation.

5.1.9.3 Improvement

The results from the study were used to improve the keyboards environmental performance over its full life cycle. Incremental improvements included re-designing the insertion cell station for reduced ergonomic impact, and identifying a suitable wall thickness so that regrind could be used in the bottom housing of the keyboard. The additional ECD criteria were taken into consideration by the CFT during the remainder of the design process. A number of innovative 'concept demonstrators' were developed using creative thinking techniques and extreme design approaches. An example of how one creative tool, the 'random word', was used to support idea generation at the improvement stage is given in Table 5-30.

Table 5-30 'Random Word' Idea Generation (Conceptual 'Hi-Rise')

Random Word	Some Characteristics	Ref.	Possible Environmental Improvement
Tree	Trunk has age rings	No. 1	Use visible method of telling age to facilitate service and EOL asset recovery.
	Biodegradable.	No. 2	Use biodegradable, natural materials.
	Many useful applications.	No. 3	Secondary applications for product, parts and packaging.
	Branches and leaves.	No. 4	Modular product with several variations.
	Sheds leaves and changes color.	No. 5	Replaceable keycaps and housings. Optional external colors.

These radical concepts were generated as benchmarks to identify long-term solutions (O' Connor *et al.*, 1999 & ADEME, 1999). The concepts attempted to take advantage of the latest ideas in ECD and to incorporate the views of the CFT and key external stakeholders. An example of one proposed concept is given in Figure 5-29.

Figure 5-29 Conceptual 'Hi-Rise' Computer Keyboard

The chosen concept incorporates the original key market requirements; being future proof, upgradeable, user-friendly and reliable. The concept consists of a number of separate modules that can be slotted in when required (Ref. No. 4, Table 5-30). These allow maximum flexibility and also offer an added feature whereby units can be sold separately, thereby creating an opportunity to increase the customer base. It is designed with defined movement and form and is adaptable for right handed and left handed users. Colors are selected to reflect corporate identity (Ref. No. 5, Table 5-30). Materials are fully compatible, standardized, and coded for recycling. Screws are replaced with clips and snap fits, and components are located to be accessible and visible, thereby facilitating assembly, disassembly and servicing. The improved clip design considers disassembly as well as assembly. Material and component reduction is achieved through industrial design and thin wall plastic technology[29]. The switch-frame

[29] New thin wall plastic technology advanced by General Electric Plastics (Trumble and Frenette, 1998).

incorporates all keys and is integrated to the top housing, while the rubber domes are incorporated onto one sheet. All modifications were re-assessed using the abridged approach.

One long-term radical improvement identified for investigation was the use of either snap fit insertion or a lower temperature, less harmful alternative to soldering. The former solution would remove the soldering stage from manufacture, thus reducing energy consumption, emissions and health & safety risks. The resulting effect on other key requirements, such as cost and reliability, would also need to be investigated. A second long-term radical improvement identified for investigation involved the use of biodegradable materials, as a replacement for plastic in the keyboard housings (Ref. No. 2, Table 5-30). This would considerably reduce the environmental impact at EOL. The effect of changing the material on other key requirements such as cost, safety, durability and ease of production would need to be investigated.

5.1.9.4 Summary of Case Study 2

In an ideal world environmental factors would always feature in the high priority list, and be integrated into the development process at all levels, from market upwards. This is not always possible due to ever shortening product development times and cost constraints. In reality, to survive in such a competitive climate, computer companies need to develop cost-effective concepts that satisfy market requirements, before they can place emphasis on environmental factors. In the case of the Hi-Rise, the Alps CFT introduced ECD once they were satisfied that the chosen concept provided the platform for success. The ECD emphasis was on incremental improvements to given design elements, rather than radical innovations. The case of the Hi-Rise is unique in that the marketing team had identified that environmental criteria were part of the basic needs of business consumers. These benefits do not include all the key criteria over the products life cycle so an ECD study was required to assess the products overall environmental performance. The study was restricted in that the work was undertaken at the detail design stage. For maximum effectiveness, ECD should take place as early as possible in the design process (Karlsson, 1997). Under these constraints, the approach chosen provided a quick, yet effective method of analyzing the environmental performance of the product during its full life cycle, and provided a platform for improvement. Through consulting the stakeholders it was possible to identify key environmental considerations that may normally be overlooked, thus highlighting the importance of stakeholder participation in ECD, and the development of a LCT. This work and subsequent transfer of knowledge was used as a platform for incorporating ECD into the Alps product design process. The Alps CFT can now take into account issues such as designing products to incorporate regrind material, and for ease of cleaning at EOL. These environmental considerations form part of the case study 'body of knowledge' included in the ECD category checklist.

5.1.10 Conclusions from Case Studies 1 and 2

It is important to integrate ECD as early as possible in the design process. The abridged life cycle approach chosen offered a quick, yet effective method of analyzing the environmental performance of the component and keyboard, while pinpointing priorities for improvement. Using tools such as flow diagrams, matrices, profiling and checklists it was possible to make incremental improvements to the design. Techniques such as creative thinking force designers to come up with innovative, radical solutions, which tend to be more long-term in nature. The abridged approach is quick, cost-effective, and allows analysis of traditional design parameters such as cost and performance, alongside environmental issues such as waste and pollutants. The assessor does not need to be a designer, or an expert in LCA, although it is helpful if they are familiar with the design and manufacturing process. In practical, real-life case studies there will always be constraints such as a lack of data, time and cost. At the same time, however small the abridged study is, the company can still gain useful data and results. Drawing boundaries reduces the depth and scale of the study; yet, it is still possible to gain practical information that can be applied immediately. The case studies reiterate how such an approach, even if completed on a small scale, can provide useful and practical results. They demonstrate that there is a way forward in ECD for SMEs without having to commit too many resources. The approach can also assist these companies to comply with legislation, by helping them to meet the requirements of the directives on environmental packaging and take-back. As highlighted by McAloone (1998) an enthusiastic approach, and driving force were shown to be key to implementing ECD. The full backing of top management was vital to the introduction of ECD in to the company, through the allowance of time and resources for employees to participate in the studies. The liaison person was critical in getting the study completed within the allotted time frame. The process requires a change in company attitude with successful ECD requiring a close co-operation and involvement with all the key product stakeholders. These product stakeholders can influence the products environmental impact. Therefore, they have a key role to play in the life of the product from design through to EOL, and stakeholder consultation should be an integral feature of the product development process. ECD raises the awareness of environmental issues in companies. This should result in improved processes, products and customer services.

Feedback

The feedback from Alps has been highly positive. They found it an extremely valuable exercise and a useful addition to their design toolbox. Variations of this approach have since been successfully applied in a number of other case studies. One limitation highlighted was the need to formalize the improvement stage. A packaging case study was carried out to test the effectiveness of one ECD improvement approach in an industrial environment. Details of this case study are provided in Section 5.3.2.

5.1.11 Summary of PCs

A 'body of knowledge' was gathered through the surveys and case studies. This can be applied in a matrix-based methodology for ECD. The next stage focuses on gathering a 'body of knowledge' and developing the methodology for a range of electromechanical products.

5.2 Electromechanical Products

The main aims of this section are:

- To identify and group key requirements and environmental considerations for a range of electromechanical products into a list of categories
- To provide relative weightings, focusing on the environmental categories[30]
- To examine the concept of involving key stakeholders in the ECD process, and to gather information on the general views of participants on a range of issues, and to make some general predictions on the next 10 years (to 2009)
- To examine EOL and MLC issues for a range of products

Details of the seven surveys (E – K) are outlined in Table 3-4. A simplified research approach for electromechanical products is given in Figure 5-30.

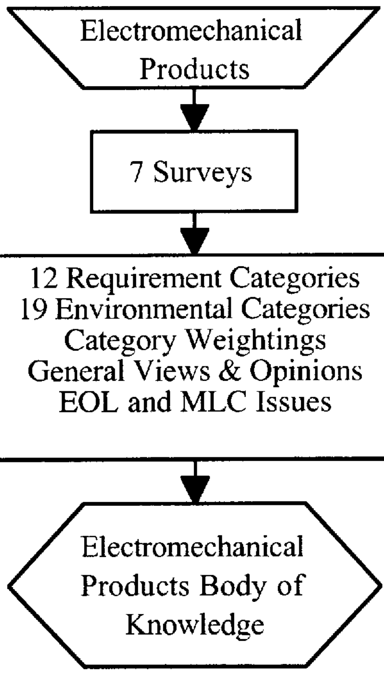

Figure 5-30 Simplified Research Approach for Electromechanical Products

[30] In surveys F to H relative weightings were developed for the environmental categories.

5.2.1 Survey E: Range of Stakeholders / Range of Products

An email survey was undertaken of a range of stakeholders for consumer durable electromechanical products. The primary aim was to get the participants to identify, categorize and weight the key requirements and environmental considerations for a range of common consumer durable electromechanical devices, i.e. washing machines, telephones, stereos etc. through open-ended questioning. Secondary aims included verifying if the categories were similar to those identified for PCs, therefore making them generic to a range of products. A questionnaire containing open-ended questions was used; Appendix A. Draft versions of the questionnaires were tested until there was a clear understanding of all sections. Questionnaires were sent to various email discussion groups, including ECD, design, manufacturing, environmental, and consumer groups, targeting a range of stakeholders. 32 participants returned the questionnaire. 50% of these resided in the U.K., 19% in other European countries, 22% in the USA and 9% in other countries. A simplified breakdown of the population is provided in Table 5-31. The population is predominantly producers (43.8%) and users (46.9%).

Table 5-31 Breakdown of the Population for Survey E

Stakeholder Grouping	%
Government	0
Producers	43.8
Users[31]	46.9
Environmentalists	9.4
Others	0

5.2.1.1 Categorization and Weighting of Requirements

The list of requirement categories was the same as those identified for PCs thus suggesting that they are generic to a range of electromechanical products. The requirements were firstly

[31] 7% of this grouping categorised themselves as 'general public'.

weighted based on 'Weighting Method A' from the pilot study, with the most frequently identified ones being 'quality and reliability', 'features and functionality' and 'product cost'. The participants also weighted all the requirements identified. The 'average weighting' profile using Table 5-4, is given in Figure 5-31. Using this technique all the requirement categories, with the exception of 'physical properties' (4), were weighted '6' or above. The top categories were 'quality and reliability', 'human factors', 'service issues' and 'supplier support'. Again, these two weighting methods produced very different profiles. These weightings include the selections of all the stakeholders who participated. The results again indicate that different requirement weightings are achieved through using different weighting methods.

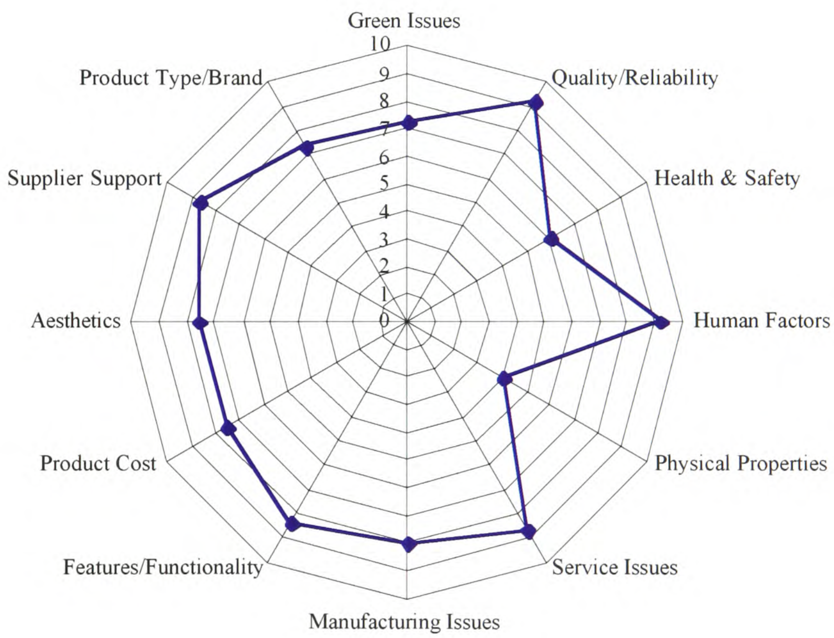

Figure 5-31 Average Weighting Profile of Requirements (Survey E)

5.2.1.2 Categorization and Weighting of Environmental Considerations

The list of environmental categories was the same as those identified for PCs, with one exception. 'Product cost' was not identified. This is not a major concern as it had already been identified as a requirement category. The results suggest that the categories are generic to a range of electromechanical products. The environmental categories were firstly weighted based on 'Weighting Method A' from the pilot study with the most frequently identified ones being 'product energy', 'health and safety' and 'human factors'. The participants also weighted all the environmental considerations identified. The 'average weighting' profile using Table 5-4, is given in Figure 5-32. The top categories were 'features and functionality', 'service issues' and quality and reliability'. Again, these two weighting methods produced noticeably different profiles indicating that different environmental category weightings are achieved through using different weighting methods. These profiles include the selections of all the stakeholders.

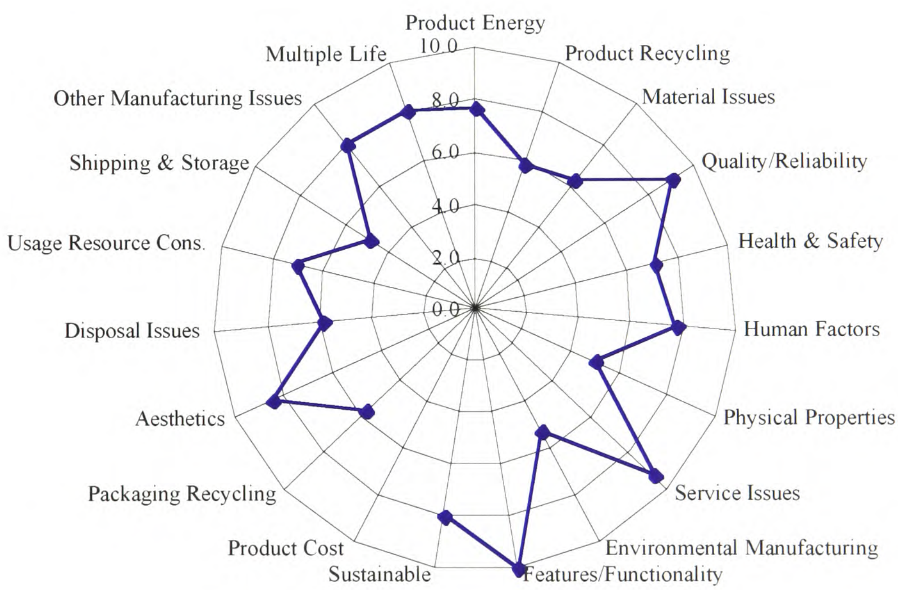

Figure 5-32 Average Weighting Profile of Environmental Categories (Survey E)

Comparing Stakeholder Grouping Selections for Environmental Categories

As the session was open-ended and the population size was relatively small at 32 participants, only the selections of the three stakeholder groupings that responded were given an in-depth examination to try and identify any notable variations[32]. The top categories are given in Table 5-32. The 'average weighting' profiles are given in Figure 5-33.

Table 5-32 Top Environmental Categories for Survey E (All, Users, Producers, Environmentalists)

All	Users	Producers	Environmentalists
Features/Functionality	Sustainable	Quality/Reliability = Features/Functionality	Product Energy

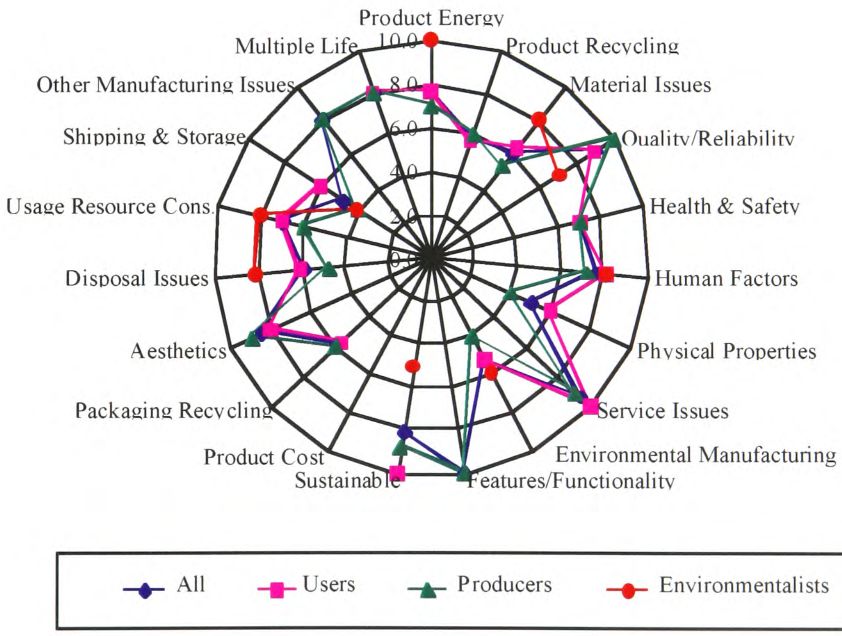

Figure 5-33 A Stakeholder Comparison: Average Weightings (Survey E)

[32] Designers accounted for 79% of the producer population.

No significant variations are evident between 'users', 'producers' and the profile of 'all' participants. Significant variations are evident between the 'producer' and 'environmentalist' weightings, Table 5-33. As the sample size for 'environmentalists' was only '3' and the session was open-ended these weightings may not offer a true reflection. Significantly 'environmentalists' gave 'sustainable' a relatively low weighting of '5' whereas 'users' gave it '8.7'.

Table 5-33 Significant Variations for Survey E (Producers/Environmentalists)

Category	Producers	Environmentalists
Materials	5.3	8
Quality/Reliability	10	7
Sustainable	8.7	5
Disposal	4.7	8

5.2.1.3 Conclusions from Survey E

The requirement and environmental categories from the study on PCs were verified for a range of electromechanical products. The remainder of the study on electromechanical products will focus on the environmental categories. The survey confirmed that it is possible to determine weightings for different stakeholder groupings that can be applied to a matrix approach to ascertain if an electromechanical product is environmentally conscious. Different weighting methods can result in different profiles. Significant variations were not found between the participant 'average weighting' of the requirement categories, and their weighting of those that were repeated in the environmental categories apart from one exception[33]. This weighting technique was preferred for the remainder of the study on electromechanical products. The results indicate a difference in opinions between 'producers' and 'environmentalists' when

[33] 'Product cost' was not identified as an environmental category.

weighting the environmental categories, although the small sample size may not be providing a true reflection. The weightings could be applied directly to a matrix for electromechanical products using the methodology outlined in the study of PCs. The environmental performance of the products could be then improved based on stakeholder preference. The study had a number of limitations, including population size. The sample population was relatively small and predominantly 'users' and 'producers', while the approach aims to include all key stakeholder views.

5.2.2 Survey F: Range of Stakeholders / Televisions and Microwave Ovens

This phase involved asking members of the Panasonic CFT to confirm and weight the key environmental categories identified in the open-ended sessions, using a closed-ended questionnaire. The primary aim of this phase was to confirm the environmental categories for two electromechanical products, televisions and microwave ovens, along with carrying out some weighting of their relative importance. The closed-ended questionnaire (Appendix A) was presented to members of the Panasonic CFT. Participants were asked to confirm the key environmental categories before weighting them. 7 of the 20 stakeholders targeted completed the survey[34]. These were as follows: 2 marketing personnel and 1 designer, packaging designer, purchasing member, manufacturing member and an environmentalist.

5.2.2.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. These environmental categories were then weighted using the scale in Table 5-4. The 'average weightings' are given in Figure 5-8 with 'product cost' and 'shipping and storage' weighted highest respectively.

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[34] Permission was not granted to make a direct approach to personnel within the company so an internal liaison person was used to deliver and collect the questionnaires.

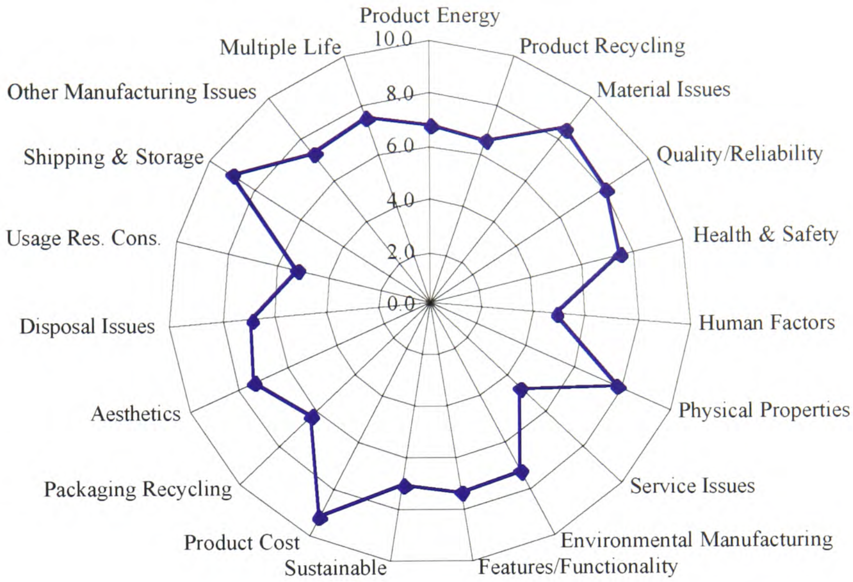

Figure 5-34 Average Weighting Profile (Survey F)

5.2.2.2 Conclusions from Survey F

The environmental categories were re-verified. Actual industrial weightings have been identified for televisions and microwave ovens albeit from a limited sample size. These are the weightings that the stakeholders purport to apply in industrial practice.

5.2.3 Survey G: Trainee Product Designers / Range of Products

This phase involved getting 9 trainee product designers to confirm and weight the key environmental categories identified in the open-ended sessions, using a closed-ended questionnaire[35]. The primary aim of this phase was to confirm the environmental categories for a range of electromechanical products, along with carrying out some weighting of their relative importance. The closed-ended questionnaire (Appendix A) was presented to the group. Participants were asked to confirm the key environmental categories before weighting

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[35] The participants were final year students from the 'Product Design' degree courses at the UOG.

them. Individually the participants had previously carried out a twelve-week ECD analysis and improvement study of the products using a range of abridged techniques including checklists, flow diagrams, matrices and profiles. The students were encouraged to use formats similar to those outlined in Figure 5-15 and Figure 5-55. From the study they developed environmentally conscious concepts. The products selected included an electric can opener, hair dryer, and a range of telephones, kettles, and toasters.

5.2.3.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. The categories were weighted using the scale in Table 5-4. The 'average weightings' are profiled in Figure 5-10 with 'material issues', weighted '7.8', being the top category.

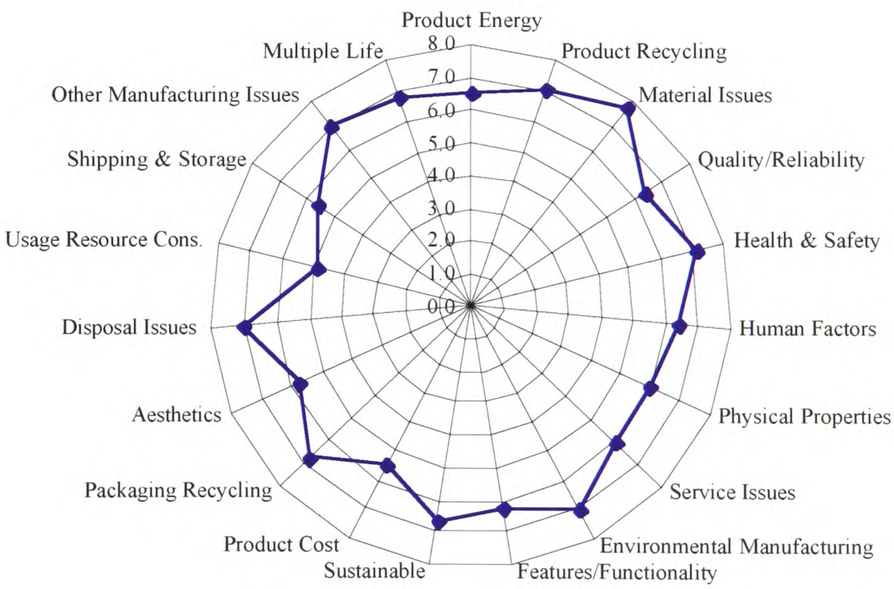

Figure 5-35 Average Weighting Profile (Survey G)

When another 12 trainee product designers, with a comparable background, were asked to carry out a similar exercise on two other groups of products, 'energy consuming' and 'non-energy consuming', no significant variations were evident, with one exception[36]. The list of products is given in Table 5-34.

Table 5-34 Other Products Analyzed (Survey G)

Category	Products Analyzed
Energy Consuming	Included a lawnmower, battery razor, personal stereo, vacuum cleaner and alarm clock.
Non-Energy Consuming	Included a hand shears, truck seat, ballpoint pen, disposable razor and inhaler.

5.2.3.2 Conclusions from Survey G

The list of environmental categories has been re-verified and a series of weightings have been identified for a range of electromechanical products. These weightings are similar to those achieved for a range of other products.

5.2.4 Survey H: ECD Experts / Three Products

This survey formed part of a focus group, discussed in Section 5.2.5, and involved getting 3 groups of 4 ECD experts to confirm and weight their environmental categories for a specific electromechanical product. The aim was to get the groups to confirm and weight the environmental categories for their respective products. A secondary aim was to compare the views and opinions of the ECD experts. The participants were presented with the list of environmental categories and asked to follow the procedure outlined in Table 5-9. The products selected were a photocopier, mobile phone and toasted sandwich maker[37].

[36] 'Product energy' was not selected as a category by the group analysing non-energy consuming products.
[37] A mobile phone was classified as an electromechanical product due to its consumption of electricity when the battery is being charged.

5.2.4.1 Confirmation and Weighting of Environmental Categories

All the participants verified the 19 environmental categories. No additional categories were suggested. The group weightings are compared against the individual ones in Figure 5-36, Figure 5-37 and Figure 5-38. The only category common to the 'top 5' for each product is 'product energy'.

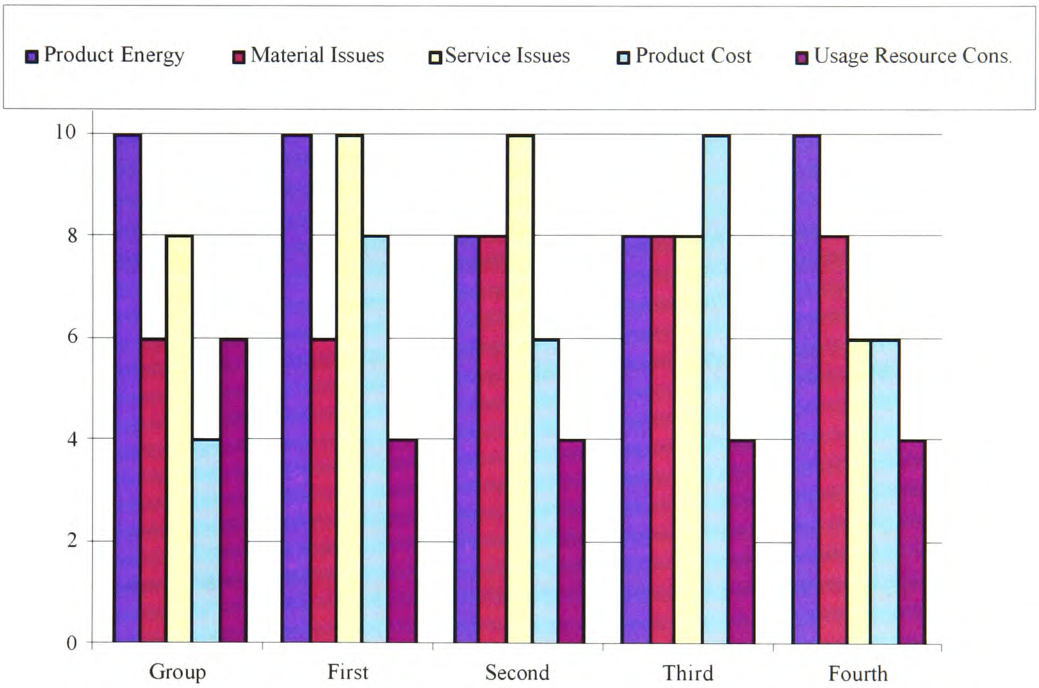

Figure 5-36 'Top 5' Category Weightings – Photocopier (Survey H)

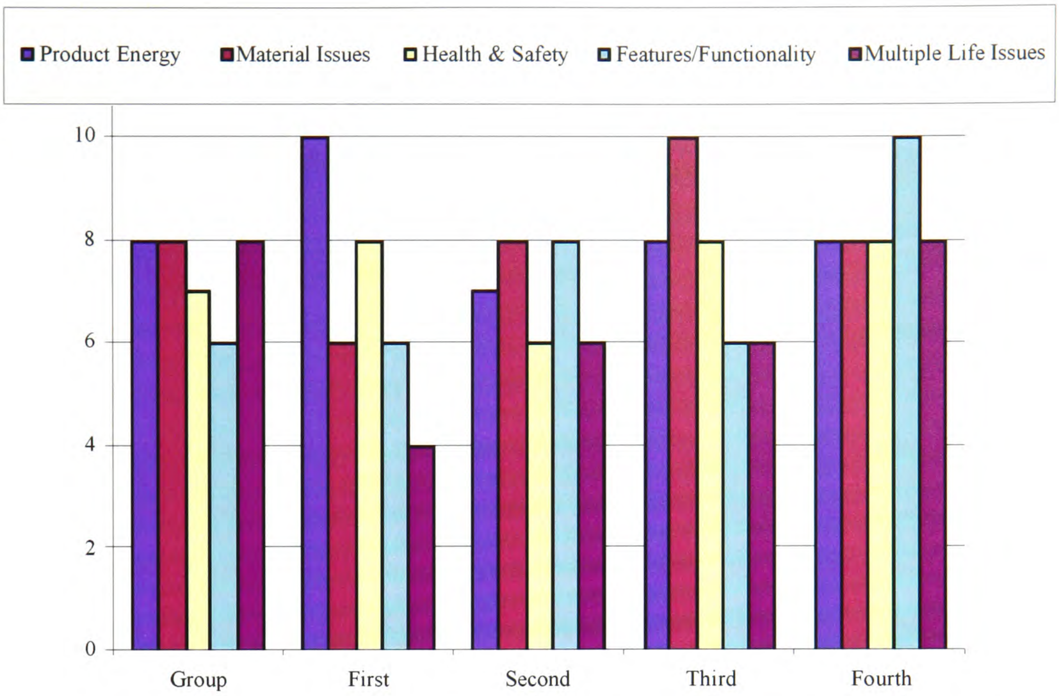

Figure 5-37 'Top 5' Category Weightings – Mobile Phone (Survey H)

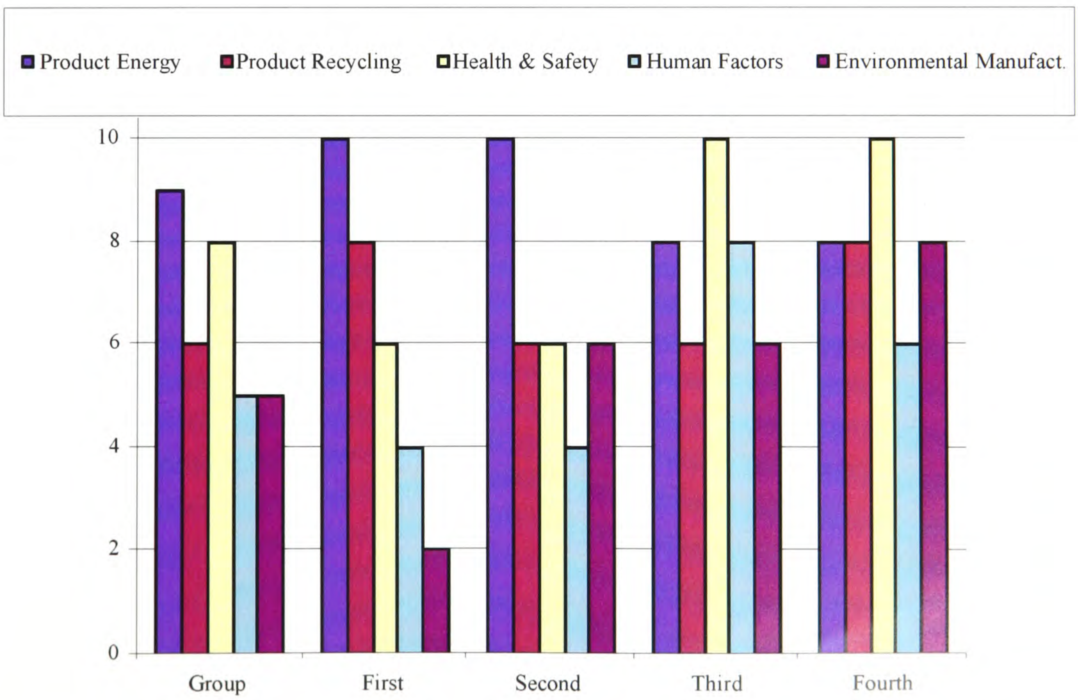

Figure 5-38 'Top 5' Category Weightings – Sandwich Maker (Survey H)

The participants felt that 'disposal issues' and 'material issues' would feature in the top categories over the next 10 years for photocopiers and sandwich makers respectively.

Comparing Views and Opinions of ECD Experts

As with 'Survey D', in terms of identifying and weighting the key environmental criteria, the views and opinions of ECD experts were found to be different. Although all the participants confirmed the categories, they did not come up with the same 'top 5'. In the group consensus weighting of the 'top 5', significant variations were evident in all three cases. When these results are added to those for the computer keyboards there are 12 categories included, Figure 5-39. 'Product energy' and 'material issues' make the 'top 5' for three of the products.

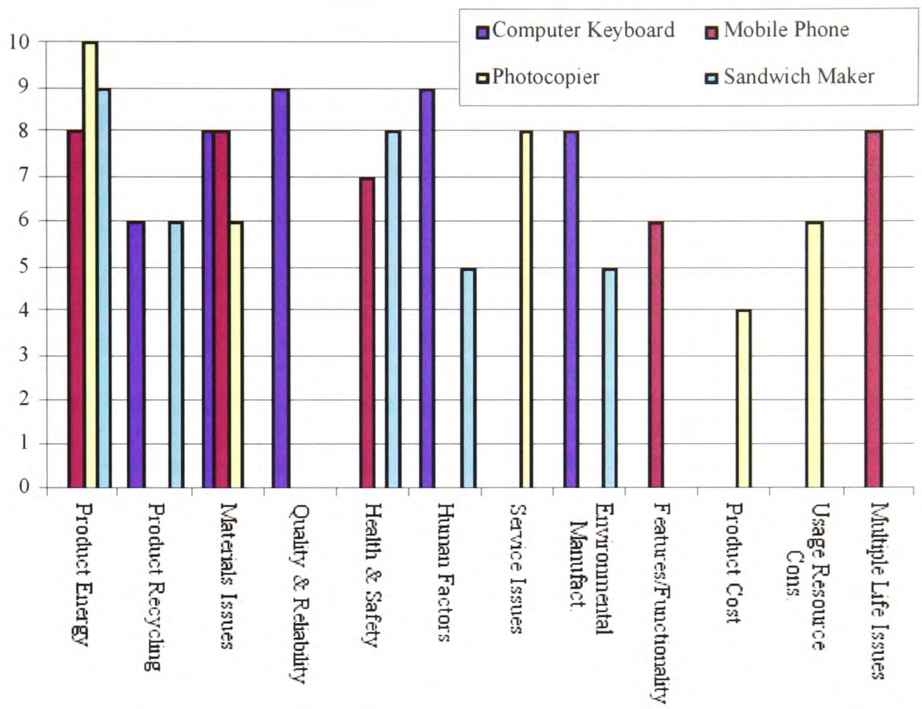

Figure 5-39 Average Weightings for 'Top 5' Categories – Four Products

5.2.4.2 Conclusions from Survey H

The list of environmental categories has been re-verified and a series of weightings have been identified for a photocopier, mobile phone and toasted sandwich maker. In terms of identifying and weighting the 'top 5' environmental criteria, the views and opinions of ECD experts were found to be different. Again, it should be noted that the participants had a limited time frame to make decisions and respondents with stronger opinions may have overly influenced the group decisions.

5.2.5 Survey I - Focus Group / ECD Experts / Four Products

This focus group was devised to encourage ECD experts to verify and weight the environmental categories and examine the concept of involving key stakeholders in the ECD process. The primary aim was to get the teams to identify and weight the key environmental categories for an electromechanical product. Secondary aims included gathering information on the general views of participants, regarding issues such as key stakeholders, influencing factors, product need and life span, and weighting of life cycle stages. Participants were also invited to make some general predictions on the next 10 years (to 2009). 16 Members of the eco2-irn forum were invited to participate in the focus group at the UOG, and apply their experiences and views as ECD researchers and practitioners[38]. Working in teams of 4, and within a 70-minute time frame, an electromechanical product was analyzed through answering a series of questions, some as an individual and some through group consensus. The participants were provided with a 1-page document to read beforehand. This document defined stakeholders and gave a brief explanation of the aims of the research. The groups were selected based on the following criteria:

- A combined minimum total of 15 years of ECD related experience
- A range of expertise to include LCA and MLC issues
- Expertise to be applicable to a range of industries
- Male and female members

The questionnaire (Appendix A) had previously under gone two rounds of piloting and modifying. The products selected were a computer keyboard, mobile phone, photocopier, and toasted sandwich maker. Some of the results have been discussed already in Sections 5.1.1.1, 5.1.4 and 5.2.4 respectively.

5.2.5.1 ECD Influences

The participants felt that a range of stakeholders would influence ECD issues over the next 10 years with the key ones being designers, government and users. Their key influences on ECD and on personal ECD opinion include a wide diversity of issues that have been grouped into a

[38] On a scale of 0 (no concern) to 4 (high concern) the participants averaged '3' on a local, national and global level.

number of key factors with numbers '1' to '7' common to both, and '8' to '10' related to personal opinion only, Table 5-35.

Table 5-35 Key Influencing Factors (Survey I)

No	Factor
1	Legislation (include. government policies)
2	Awareness
3	Costs
4	Societal Behavior[39]
5	Research & Development/New Technology
6	Media
7	Resource Availability
8	Manufacturing Issues
9	EOL Issues
10	Future Forecasts

An awareness of these influencing factors can facilitate companies in developing long-term ECD strategies. The number of personal influences highlights the possible variance in categories and weightings for a range of products. For example, considering the influence of 'media', Lundie and Huppes (1999) found that the more an environmental issue is discussed in public, the broader the range of preferences in weighting environmental categories. These factors can be used in conjunction with the list developed by McAloone and Evans (1997) to improve the companies overall ECD effectiveness and efficiency, Table 2-2.

5.2.5.2 Sustainable Need

Using the 'sustainable needs scale' in Table 5-36, and through group consensus, all the participants predicted that the need for a computer keyboard, photocopier, and toasted

[39] This includes a range of issues such as population increases, effects of working and living environment, world ethics, culture and globalization.

sandwich maker would greatly reduce over the next 10 years, Figure 5-40. They felt that the very low rating for the mobile phone would remain the same in 10 years time.

Table 5-36 Sustainable Needs Scale (Survey I)

0	2	4	6	8	10
Not Required	Very Low Need	Low Need	Medium Need	High Need	Vital for Maintaining Life

The mobile phone and sandwich maker have a very low need in terms of sustaining life but they have become products that users have a preference for, and are therefore manipulated to consume faster ('Reason No. 4', Table 1-3). If consumers keep purchasing these products, then companies need to ensure that the products are designed to be environmentally conscious[40]. The forecasted reduced need for the computer keyboard and photocopier in 10 years time can be linked to technological progress ('Reason No. 7', Table 1-3), i.e. speech recognition engines replacing computer keyboards as input devices. Email has already begun to affect the usage rate of photocopiers.

[40] It is estimated that the total mobile phone subscribers world-wide will double between 2000 and 2002 (Booz Allen & Hamilton Analysis cited in Waters, 2000).

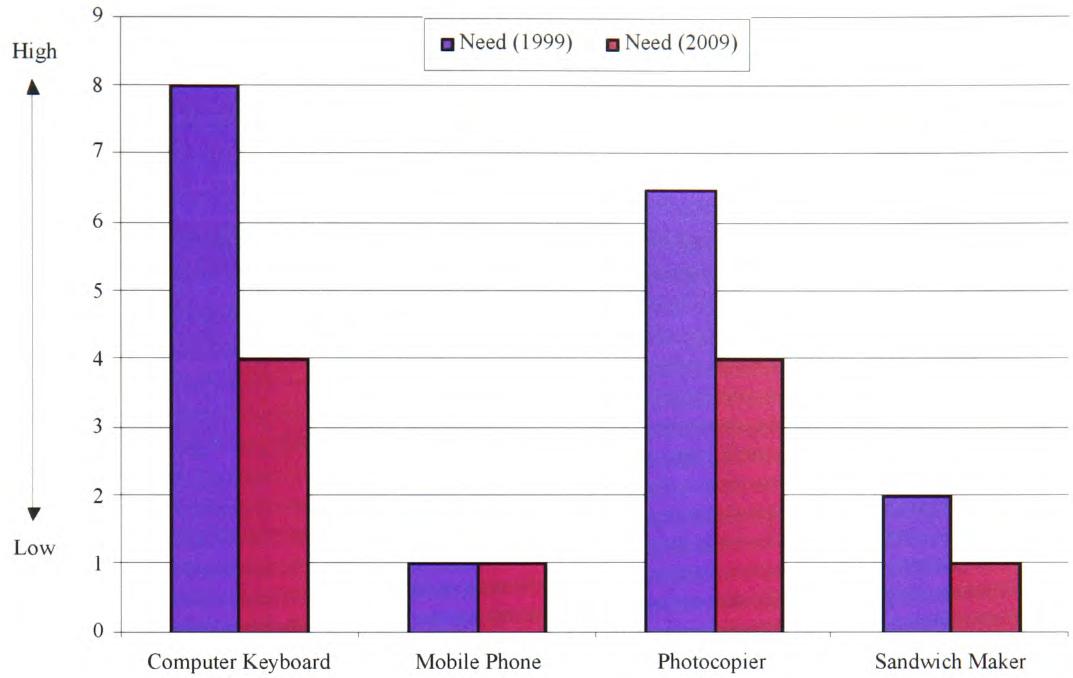

Figure 5-40 Product Need Scale for Four Products

This 'sustainable need' approach can be linked to the 'conceptual approach' outlined in Chapter Two, that questions the product concept from an environmental perspective and in the context of sustainable development (Van der Horst and Zweers, 1994). Although companies will continue to produce products of very low sustainable need, their rating on the scale should be considered when completing an ECD evaluation. It can then be used to assist in scoring the 'sustainable' category.

5.2.5.3 'Ideal' Product Life

Participants were asked to come to a group consensus regarding how many years they would ideally expect their assigned product to be used for in its intended function, Figure 5-41.

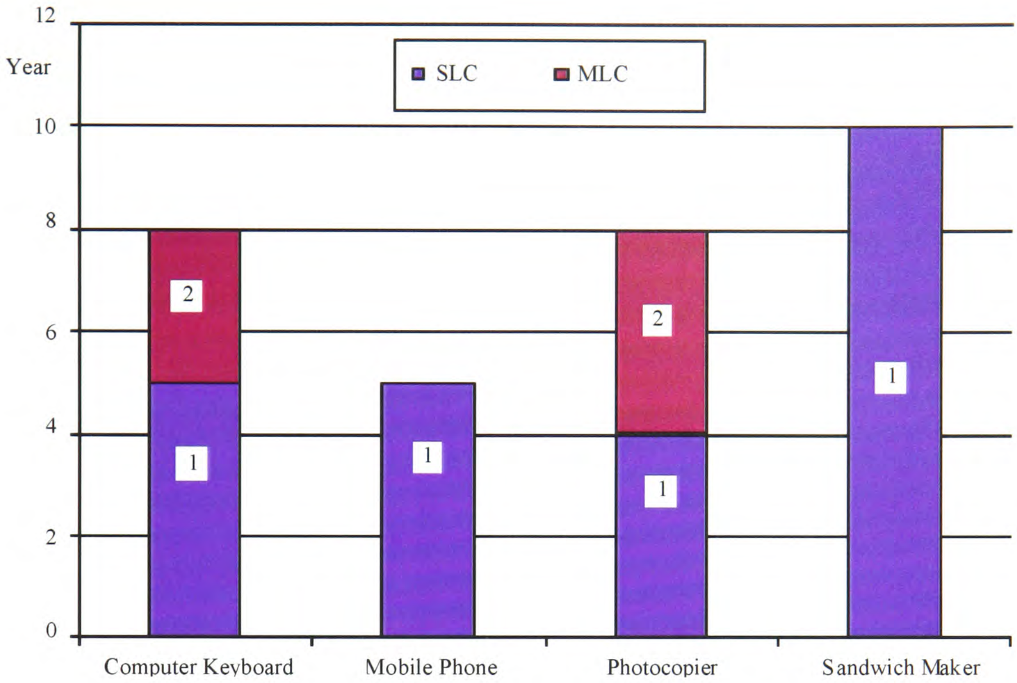

Figure 5-41 'Ideal' Single and Multiple Lives for Four Products

The 'ideal' computer keyboard life is similar to that for a typical life for a personal computer outlined in Kostecki (1998), Table 1-2, except that the keyboard is remanufactured once before retirement. The 'ideal' life for a photocopier is similar to the estimated life identified in the section on EOL asset management (5.2.7.1) with the product remanufactured to allow a second life. For the mobile phone this 'ideal' life reflects the rapid advancements in technology and the ongoing miniaturization of the product and would seem to be much longer than the current scenario[41]. These products need to be easily upgradeable by the user to incorporate new technology and styles caused by social pressures, i.e. replacing the phone cover. The long single life span for the sandwich maker reflects a used image problem. Also, it does not contain many valuable components, and is unlikely to be upgraded to reflect technology changes. Secondary lives for the mobile phone and sandwich maker would be for materials and components, rather than the product.

[41] In a separate study of 5 users, by the author, all of them had replaced their handset after 12 month.

5.2.5.4 Weighting of Stakeholders

Participants were asked to arrive at a group consensus regarding the importance of the different stakeholders in identifying and weighting the key environmental considerations for their product by using Table 5-4. The stakeholders weighted highest were a designer, materials expert, manufacturer, government and EOL asset manager respectively. The participants expressed difficulty with this task in both making the decisions on each particular stakeholder, and in reaching a group consensus. They felt that all stakeholders could be seen as important but that applying weightings to them may not be a practical approach.

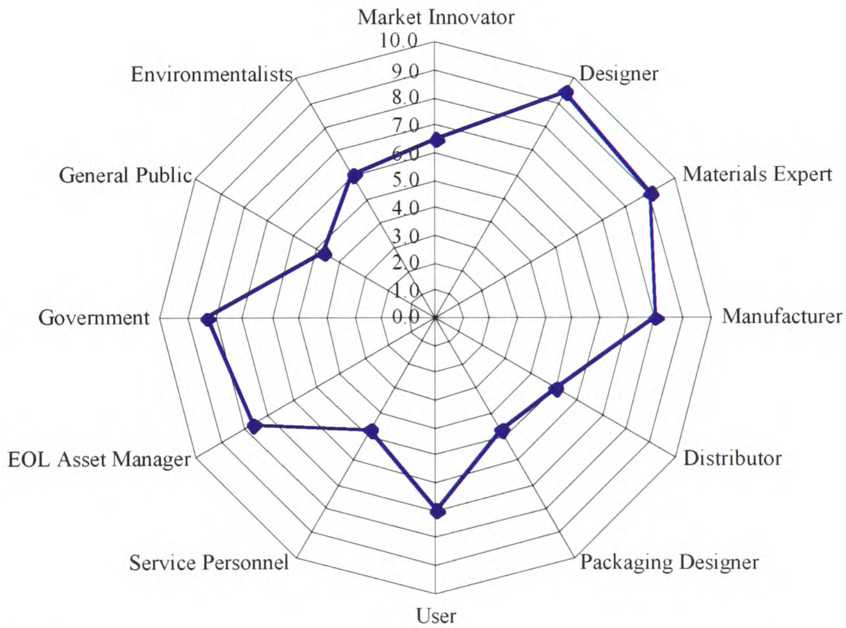

Figure 5-42 Average Weighting of Stakeholders for Four Products

5.2.5.5 Weighting of Life Cycle Stages

Participants were asked to come to a group consensus regarding the importance of key life cycle stages in the environmental impact of their assigned product-using Table 5-4. Significantly different profiles are evident for all stages, with one exception, 'MLC', Figure 5-43. 'MLC' includes options such as collection, storage, remanufacture, reuse and recycling.

'EOL disposal' includes collection, storage, and options such as shredding and compaction, incineration, and landfill disposal. Again, the participants expressed difficulty with this task in both making the decisions on each particular stage and in reaching a group consensus. They felt that all stages could be seen as important but that it was difficult to make a decision without having further information available to them. The group analyzing the computer keyboard assumed that distribution was part of the PCs and thus could be ignored here.

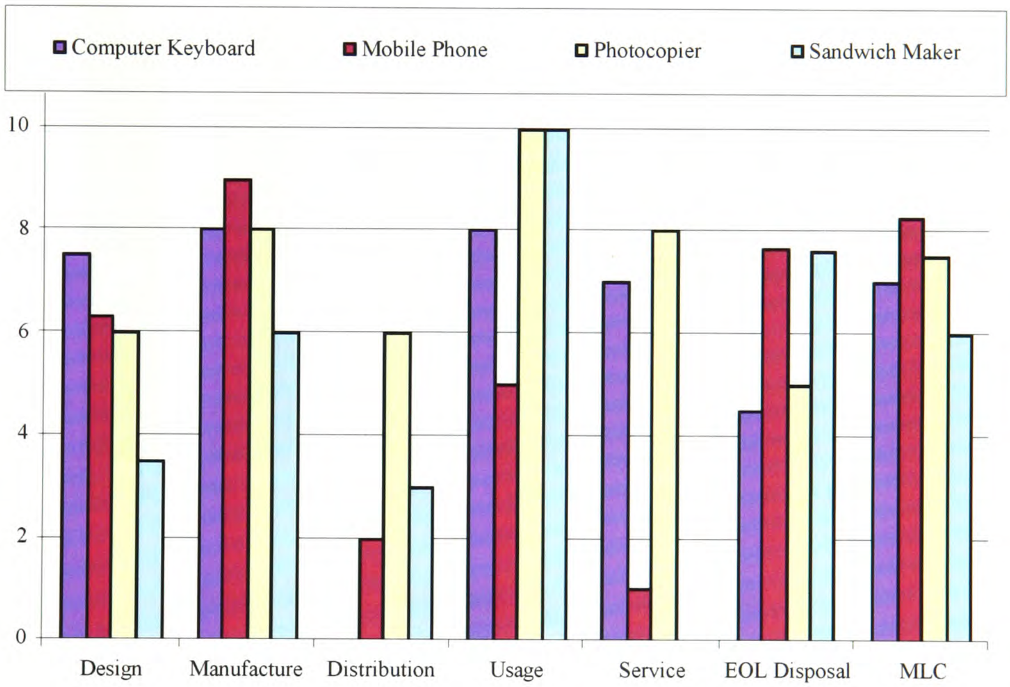

Figure 5-43 Weighting of Life Cycle Stages (Range of Products)

Two design members of the Alps CFT, 'Survey B', were also asked to decide the importance of key life cycle stages in the environmental impact of PCs, using a separate questionnaire (Appendix A) and the scale in Table 5-4. Once more, they found the task very difficult. Significant variations were noted in their selections for all but two of the stages, 'manufacture' and 'distribution', Figure 5-44. When the average weighting for the two designers are charted against the computer keyboards weighting, quite similar profiles were evident, taking into account the computer keyboard distribution is part of the PCs, Figure 5-45.

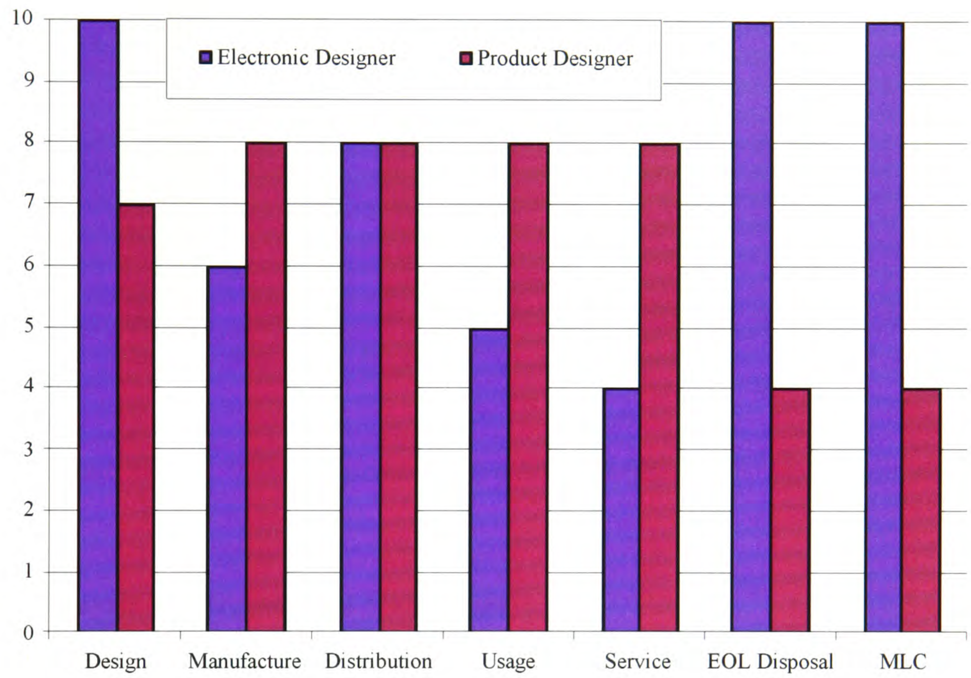

Figure 5-44 Weighting of Life Cycle Stages (PCs)

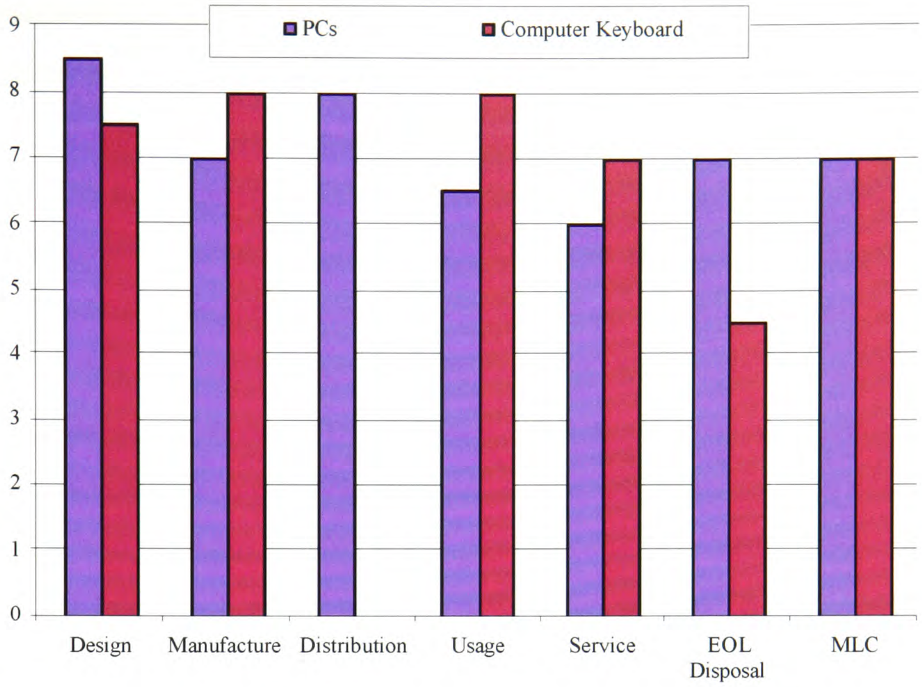

Figure 5-45 Weighting of Life Cycle Stages (PCs & Computer Keyboard)

5.2.5.6 Generic Environmental Categories

The participants were asked to gain group consensus on whether the list of environmental categories generated in the previous studies was specific to one industry, applicable to a range of industries, or generic, and therefore applicable to all industries. They also had to decide if the list was specific to one product, applicable to a range of products, or generic, and therefore applicable to all products. The groups, who reviewed the computer keyboard, photocopier, and sandwich maker, felt that the list could be applied to all industries and products. The group who completed the mobile phone study opted for application to a range of products and industries. They felt they would have to look at the categories in more detail before making a final decision[42].

[42] Follow on discussions of some of the key topics of the focus group was carried out through email.

5.2.5.7 Conclusions from Survey I

The focus group participants felt that a range of stakeholders would influence ECD issues over the next 10 years, with the key ones being designers, government and users. Their key influences on ECD and on personal ECD opinion included a wide diversity of issues that were grouped into a number of key factors to facilitate in ECD research and practice. Other varying factors that could influence the results are discussed in detail in Section 5.4. All the participants felt that the need for the computer keyboard, photocopier and sandwich maker would greatly reduce over the next 10 years. The sustainable need scale can be used to assist in scoring the 'sustainable' category. The participants devised 'ideal' product lives for their products. These will be discussed later in the context of the ECD methodology. The section on weighting the importance of the different stakeholders resulted in a designer, materials expert, manufacturer, government and EOL asset manager being weighted highest respectively. The participants expressed difficulty with this task, indicating that it may be difficult to reach a consensus on their relative importance. The two exercises in weighting life cycle stages resulted in significantly different results between product to product and from stakeholder to stakeholder thus pointing out that it may be difficult to reach general agreement on their relative importance. Within a product family, the results were similar. The participants expressed difficulty with this task of weighting life cycle stages. The groups, who reviewed the computer keyboard, photocopier and sandwich maker felt that the list of environmental categories could be applied to all industries and products. The group who completed the mobile phone study opted for application to a range of products and industries. Again, it should be noted that the participants had a limited time frame to make decisions, and respondents with stronger opinions may have overly influenced the group decisions. The next stage in the development of the ECD methodology was to check the validity of the EOL asset management results from 'Case Study 2', and determine if they were specific to computer keyboards, or generic to a range of electromechanical products. Also, through a survey of an established industry, some of the key MLC factors were established for application through a generic matrix based framework.

5.2.6 Survey J – Range of EOL Stakeholders / Range of Products

The 'Hi-Rise' keyboard case study involved interviewing a number of personnel from one EOL asset management company, AuI. These interviews resulted in a list of environmental criteria for the EOL asset management of computer keyboards. To check the validity of these results and determine if they were specific to computer keyboards or generic to a range of electromechanical products, the study was expanded to include four other EOL asset management companies. These companies were selected on the basis of their EOL asset management strategies. After an initial email, and telephone selection survey, it was found that although many companies claimed to carry out full EOL asset management of electromechanical products, the majority were simply removing components of obvious value from the products, for testing, repackaging and resale into secondary markets. The remaining products were shredded to reduce the volume of material for landfill. The four additional EOL asset management companies selected for the study were Multis Ltd., The Mann Organization, Recoverex Ltd., and Electronic Recycling. These Irish based companies were interviewed over a period of one week. The primary aim was to check the validity of the information gathered from AuI in the keyboard case study, through identifying EOL routes, levels and key environmental criteria for asset management of electromechanical products. Secondary aims included determining the role of stakeholders in EOL asset management, and ascertaining if the views and respective selections of expert stakeholders are comparable with each other. Senior managers at the companies were selected for interviewing. In the preliminary selection survey, these participants demonstrated a high level of knowledge of the industry and the products being recovered. The interviews were informal and semi-structured; using predominantly open-ended questions, and lasted between one and two hours. A frame of reference was used for respondents' answers, but there was a minimum of restraint on the answers and their expression; Appendix A.

5.2.6.1 Results from Survey J

All of the companies dealt with a range of EOL electromechanical products, and worked closely with a range of other EOL companies to ensure full asset management took place. The respondent's verified that the seven EOL asset management strategies identified by AuI were generic for all the electromechanical products they were familiar with. They again suggested that EOL asset management recovery for reuse could take place at three main levels for electromechanical products. The levels can be further sub-divided as shown in Figure 5-46 to Figure 5-48.

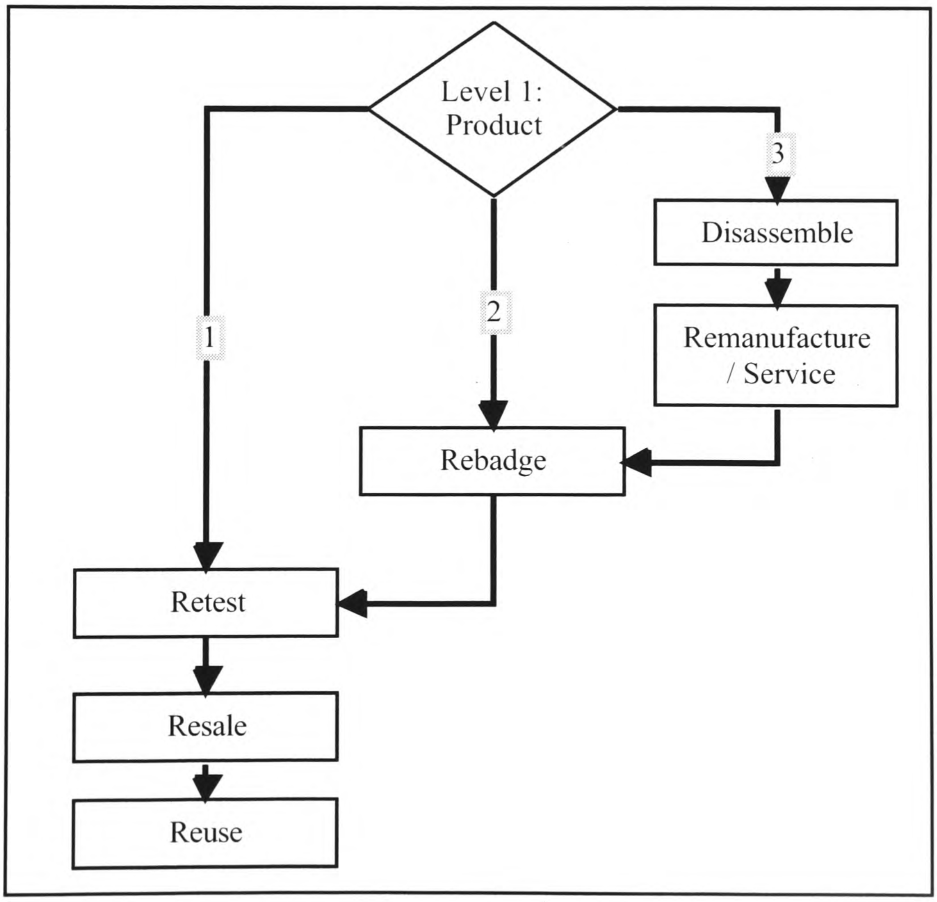

Figure 5-46 EOL Level 1: Product Asset Management

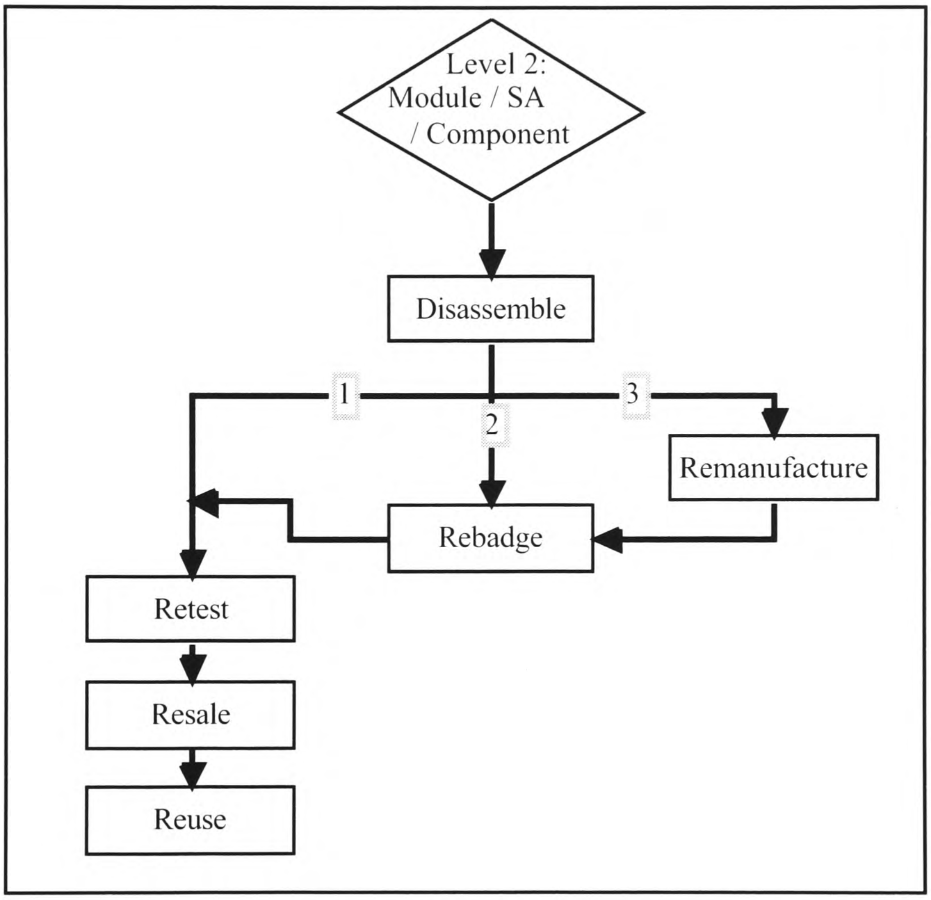

Figure 5-47 EOL Level 2: Module/SA/Component Asset Management

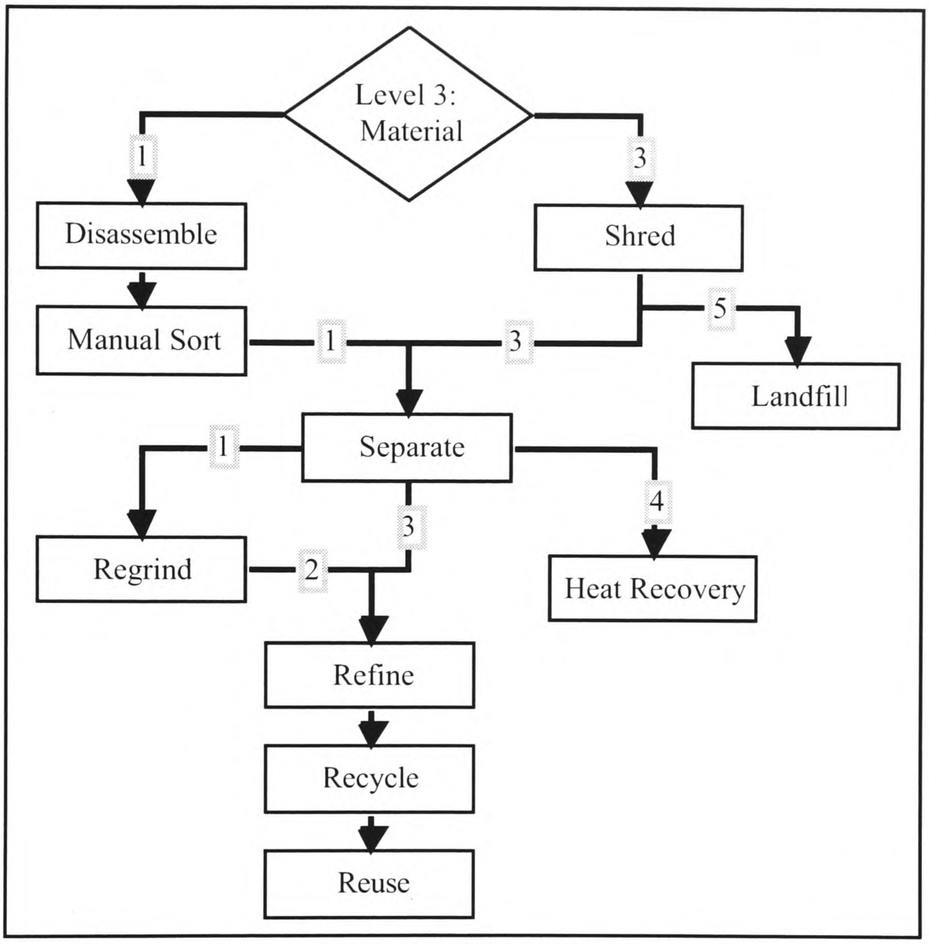

Figure 5-48 EOL Level 3: Material Asset Management

The participants generated lists of key environmental considerations, for EOL asset management of electromechanical products. These were all found to be very similar to the list generated by AuI. However, there was some disagreement regarding the importance of manufacturers supplying the EOL asset management companies with parts, component and materials lists, and the percentage materials by weight in the products. Despite the wide range of electromechanical products arriving for EOL asset management, two of the companies felt that they had enough expertise and technology to identify the product constituents quickly and effectively, without the need of detailed lists from the manufacturers. They thus assigned low importance to this consideration. In terms of identifying the key environmental criteria through open-ended questioning, the views and opinions of EOL asset managers were found to be similar. A clear difference in opinion was evident when assigning importance to the criteria. The participants were not requested to weight the considerations in a closed-end session. All of the participants interviewed felt that they should have a key role in ECD. They also felt that they would become more directly involved over the next 5 to 10 years. The participants also felt that other stakeholders should have a role in EOL asset management. The role of 'users' could include purchasing recycled and remanufactured goods. The 'producers' role could involve using recycled materials, incorporating remanufactured components in new designs, and providing the necessary product information to EOL asset managers. Once again, they felt that these other stakeholders would become more directly involved in EOL asset management, and ECD, over the next 5 to 10 years.

5.2.6.2 Summary of Survey J

This section confirmed the strategies, levels, and key environmental considerations for EOL. It also established that EOL asset managers have a key role to play in ECD, while suggesting that other stakeholders have a key role to play in ensuring optimum asset management. This information should be used in designing electromechanical products for EOL asset management. Although the views and opinions of EOL asset managers were found to be similar in terms of identifying environmental criteria through open-ended questioning, a clear difference in opinion was evident when assigning importance to the criteria.

5.2.7 *Survey K - Range of Stakeholders / Photocopiers and Facsimile Machines*

A survey of an established MLC industry was undertaken to aid with the development of the ECD methodology. This survey of OA equipment in the U.K. focused predominantly on the collection, and remanufacture, of photocopiers and facsimile (fax) machines. It involved gathering information on EOL asset management approaches, collection systems, and demand for recovered products, re-manufacturing processes, and future forecasts through consulting a range of key stakeholders. These stakeholders included manufacturers, product dealers, environmental experts, EOL asset management companies and government departments. The European Trade Organization for the Telecommunication and Professional Electronics Industry (ECTEL) had previously carried out a detailed study on EOL management of cellular telephones (ECTEL, 1997). The results from the ECTEL study will also be referred to here. This study was aimed at establishing some of the key factors behind the success and/or failure of photocopiers and fax machines in terms of a MLC. These factors would then be applied to other electromechanical products through a generic matrix-based framework. The study was conducted over a period of 3 months in 1998. The list of environmental categories (Table 4-6) included 'multiple life cycle issues'. Some EOL criteria were established in the 'Hi-Rise' case study, and the study of a range of EOL asset managers. The factors that influence a MLC were yet to be established. Using informal interviews, telephone conversations, postal and email questionnaires, the study was divided into three parts, that ran as much as possible in parallel:

- Survey of product dealers, using the questionnaire structure given in Appendix A.
- Survey of a range of stakeholders including manufacturers, university researchers, industrial opinion formers and government regulators, using the questionnaire structure given in Appendix A.
- Survey of EOL asset managers (including re-manufacturing personnel), using a combination of both of the previous questionnaire structures.

Over 60 people, all based in the U.K., were targeted through telephone, postal, email and informal interviews, with 38 of them agreeing to participate. A number of prominent manufacturers actively participated in the survey. Other stakeholder groupings such as government regulators were chosen from various databases. All the 'expert' personnel were selected because of their knowledge and experience in environmental affairs, and their ongoing activities in environmental issues, contributions to the development of industrial standards and regulations, and environmental technologies. These are the people who will influence the development of environmental policies and regulations in the coming years. A simplified breakdown of the population is provided in Table 5-37. Again, all stakeholders involved in the production and delivery of the product to the user, are included in one group termed 'Producers'. The population is predominantly producers (60.5%) and EOL asset managers (21.1%). Participants were prepared, on average, to spend a maximum of 40-45 minutes being interviewed. A summary of the initial results and conclusions drawn from this study are given in O' Connor and Blythe (1999).

Table 5-37 Breakdown of the Population (Survey K)

Stakeholder Grouping	%
Government	10.5
Producers	60.5
Users	0
Environmentalists	7.9
Others	21.1

5.2.7.1 The Products

The photocopier and fax machines were examined in terms of SLC and MLC options. These products are very different in nature; two key differences being method of sale and product price. Fax machines tend to be predominantly sold outright while photocopiers tend to be predominantly leased. Also, the fax machine is relatively inexpensive, and seen as a disposable item at EOL. Parallels can be drawn with telephones and computer keyboards that also tend to be shredded and disposed of. Photocopiers like automobiles are expensive to purchase, and are thus much more likely to be returned for remanufacture or recycling. The first life cycle of the photocopier was estimated at between 3-5 years, while the fax machine life was estimated at between 5 to 8 years, with photocopiers being serviced more frequently. The key customer requirements identified by the dealers were cost, performance, service, and supplier support. Their key 'green' considerations included the use of recycled paper, and a concern for ozone depletion and emissions. All the dealers felt that there was a small increase in the demand for 'green' products.

5.2.7.2 Second-hand Market

There is an established market for second-hand photocopiers both in the U.K. and worldwide. Current demand for second-hand fax machines is low. The participants predicted that the market for second-hand photocopiers, and the electromechanical product re-manufacturing industry would continue to grow over the next 5 to 10 years. The main reason that dealers currently offer remanufactured products is customer requests on cost. Five main routes were identified for the EOL asset management of photocopiers:

- Product reuse (including sale to traders for export)
- Product remanufacture for resale into secondary markets
- Material recycling and component recovery and reuse through disassembly and sorting
- Material recycling through volume reduction, shredding and separation techniques
- Disposal

Most fax machines are never returned to the dealers. When fax machines reach EOL they may be stored at the company's premises before eventually being collected by the local authorities or by specialized waste contractors for safe disposal. A small number of fax machines are resold into secondary markets or collected by EOL asset management companies for material recovery.

5.2.7.3 Re-manufacturing

All of the dealers and manufacturers interviewed already carried out some re-manufacturing. The two largest companies, Canon Re-manufacturing U.K. Ltd (Canon) and Ikon European Re-manufacturing Ltd. (Ikon) are discussed here.

Photocopier Re-manufacturing Process

Canon and Ikon have established recovery and re-manufacturing facilities for photocopiers. The reason these companies offer remanufactured products include cost benefits, regulations, waste reduction, environmental policy, and corporate image and customer requests on environmental consciousness. The products are predominantly collected in the U.K., with some coming from other countries in Europe. Photocopier remanufacture typically involves a number of manual stages as shown in Figure 5-49.

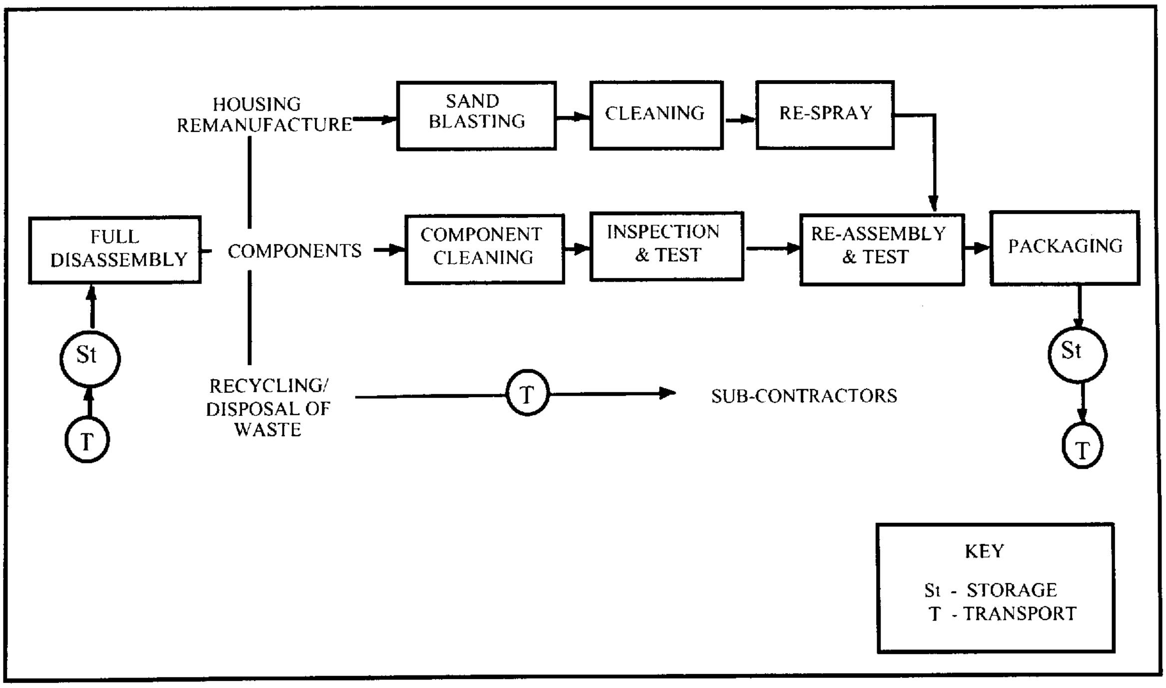

Figure 5-49 Typical Stages in the Remanufacture of a Photocopier

Up to 60% of the photocopiers they handle end up being remanufactured with the remainder being disassembled for spare parts, and sent for recycling. Normally, their remanufactured machines sell at an equivalent price to the new versions, and with the same guarantee and appearance[43]. The companies will usually remanufacture a product at least once, but depending on the volume of copying, age of the machine, and the availability of spare parts they may remanufacture a number of times. Ikon applies the companies own remanufacture logo.

Fax Machine Re-manufacturing Process

Re-manufacturing of fax machines is not as common and there was very little specific information available. Typically, the process involves a number of manual stages, which are similar to Figure 5-49. Normally, the remanufactured machines are of similar appearance to the new versions, sell at a lower price, with a different guarantee. The companies will usually remanufacture a fax machine only once.

Sales to Trade

The trade industry is dominated by supply and demand, and is influenced by political and social issues, i.e., the market could change if living standards change. This second-hand sales chain can often involve up to five different companies, located in several different countries, from when it leaves the previous owner to when it arrives at the new one.

5.2.7.4 MLC Considerations

The key elements of a product take-back system were outlined in the ECTEL study. Some potential benefits identified included reduced manufacturing costs due to reuse of components, more control over the company's product portfolio, the opportunity to improve the design of future products by analysis of returned products, and improved corporate image. The ECTEL study also highlighted public awareness and the recycling infrastructure as two key barriers to

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[43] Some companies sell the product as low as 33% of the original cost.

take-back success (ECTEL, 1997). The product requirements which have caused the use or acceptance of re-manufacturing in the OA industry include; the relative cost of re-manufacture compared to new product cost, reliability, cost of disposal, customer perception, environmental awareness, cost avoidance (purchase of raw materials), commitment to reducing landfill, and legislation[44]. The key factors that participants in this study felt would affect a MLC have been grouped into six main headings, and are listed in Table 5-38. These are not presented in any particular order of importance.

Table 5-38 MLC: Six Key Influencing Factors

No	Factor	Considerations
1	Cost	Will it be cost effective for the product to have a MLC? Consider issues such as profit, economy and target market.
2	Awareness	Is the awareness level sufficient for a MLC product? Consider issues such as customer perception, environmental awareness, education and the role of environmental organizations.
3	Product Issues	Is the product suitable for a MLC? Consider issues such as new technology, technology advances, quality, reliability, function, upgrading, guarantees, supply of parts, servicing and understanding EOL options (i.e., contamination).
4	Legislation	Is the legislation favorable towards a MLC product? Does the industry use a recognized set of terminology for new and MLC products? Consider issues such as new and impending legislation, government policies, and the use of standardized terminology.
5	Infrastructure	Is the infrastructure in place for a MLC product? Consider issues such as funding, collection, storage availability and globalization.
6	Stakeholder Co-operation	Are the mechanisms in place for stakeholder co-operation? Ensure closed-loop co-operation, with the views of a range of key stakeholders considered.

44 Some of the contacts expressed the view that a new quality standard for multiple life cycle products, driven by both recycling and trade associations, would be developed over the next few years.

Factor 1: Cost

Costs will always be an issue so it is important that the government ensures a level playing field. The system needs to be cost effective for dealers and re-manufacturers, as well as providing an incentive for customers to return the used product. Processing used equipment can yield significant cost advantage in remanufacture, and the reclamation of spares and components. In a booming economy clients can afford to purchase new products, thus a MLC may not be the preferred option. Here, manufacturers could target their major clients, and encourage them to purchase a certain percentage of remanufactured goods. A potentially good market for remanufactured machines could be universities, because they tend to have a larger number of the younger 'deep green' consumers attending, and also traditionally have a limited budget from which to purchase new products[45].

Factor 2: Awareness

If all affected parties are concerned with the environment, and aware of the common environmental impacts, there is an increased likelihood of success. There is a steady growth in the level of environmental awareness of U.K. consumers, especially among the younger generation, who will greatly affect purchasing decisions over the next few years. Consumer awareness can be raised through promotion and education, and they should be encouraged to lease machines. Ikon promotes their re-manufacturing business through factory tours for large prospective major clients. In the survey, the majority of the dealers felt that consumers who currently purchase remanufactured machines were doing so, as they 'looked the same as a new one', cost less, and they were generally willing to accept a lower level of quality and reliability. If consumers are aware that the quality and reliability of a remanufactured machine are equivalent to new machines, they are more likely to purchase them, especially if they cost

[45] It is important to distinguish between the 'deep greens' (i.e. those who base their purchasing decisions on environmental issues) and the 'pale greens' (i.e. those who are concerned with environmental issues but who do not necessarily base their purchasing decision on them).

less and have similar service guarantees. It is also important to keep educating consumers in relation to machine usage. In products such as photocopiers, duplexing and power saver modes need to be improved, and the communication of how to use them developed and implemented. Environmental organizations can also have a large influence. Greenpeace have given an official stamp of approval to machines remanufactured by Ikon and are prepared to pay the same amount for them because of the environmental benefits.

Factor 3: Product Issues

Design for reuse, disassembly and recycling is fine in principle, as long as technological advances do not make the designs obsolete ('Reason No. 7', Table 1-3). The computer industry is one example where technological advances regularly deem equipment obsolete. Substantial advancements in fax technology every few years have resulted in little or no remanufacture of fax machines. Growing use of email has affected the volume of copies per photocopier machine over the last few years thus extending their first life. Products have largely been designed to sell instead of considering resource use and sustainability. Do consumers really need all the sophistication in current products? Maybe a more basic product would be sufficient, along with possibly being easier to remanufacture and service? Companies should aim to offer the same guarantee with a remanufactured machine as a new model. Every effort should be made to incorporate recycled materials into new designs. This would obviously result in a greater demand for recovered materials and greatly improved material flows. Xerox have demonstrated that the best environmentally conscious design is the most cost effective overall (deJong *et al.*, 1999). All products should be designed to be modular and upgradeable. Companies need to prioritize these criteria at the design stage. With re-manufacturing there are quality, reliability and legal issues, i.e., what can a company remanufacture and resell, if the company offers remanufactured goods can they also offer the required quality? A key to the re-manufacturing industry will be the supply of parts. The automobile industry would collapse without the supply of parts. Part replacement in cartridges involves working closely with cartridge manufacturers to ensure a supply of spare parts. Presently, manufacturers will supply parts for photocopiers a maximum seven-year period. Companies need to be able to demonstrate the same level of function and quality using second-hand parts. Xerox put reused components through the same rigorous testing as new components. Extended product life through EOL asset management can improve the service function for Hewlett Packard through increasing part availability and lowering costs (Kostecki, 1998). A greater understanding of EOL options is also required. In the OA industry, contamination is a key issue, i.e., the photocopier drum base material is recyclable if the contaminating chemicals can be removed. Waste separation at disposal is another major issue, i.e., companies need to be able to remove toxic constituents from recyclable materials, or otherwise the products will get treated for safe disposal, but not recycled. It is imperative that the optimal EOL route is selected. One way of focusing on reducing waste is through remanufacture, although when the product eventually reaches EOL there will still be waste and disposal issues. The environmental benefits of remanufacture need to be balanced against the environmental effects associated with completing the process, i.e., emissions or energy consumed. Thus, it is a very complex process.

Factor 4: Legislation

The new take-back legislation will force companies to examine re-manufacturing, as it may offer a more cost-effective alternative than recycling or disposal. Further legislation could force manufacturers to remanufacture a certain percentage of their products. Tax incentives may be offered to companies who remanufacture a certain percentage of their products while landfill tax will place pressure on companies to look at options other than disposal. Taxing of resources is also an option, i.e., tax on companies who use precious metals and also on using environmentally damaging transport. The government could also either offer incentives or force companies to purchase a certain percentage of remanufactured products. A common set of terminology needs to be defined. Terms such as 'recycle', 'remanufacture', 'refurbish', 'rebuild' and 'recondition' are not clearly defined. Canon used the term 'remanufactured' while another used the term 'new-built' for the same type of machine. Kodak distinguish between re-manufacturing and refurbishing through defining re-manufactured product as those which are returned to the manufacturing plant for a complete overhaul while products can be refurbished in a local workshop (Kostecki, 1998). Legislation needs to define recycling in terms of what the output should be, i.e. what should be achieved. A lot of companies claim to be recycling but in reality they are just shredding for disposal. The definition of sustainability is also a key issue. If the carbon dioxide emissions from road transport vehicles are rectified by the natural habitat through recycling into oxygen, can we call this a sustainable system? In this situation sustainability is looked at in terms of the pollution effects caused. Considering the latter statement, if companies can design photocopiers to last for 'X' number of years and then degrade back to the natural elements, are they sustainable? There are many problems with the terminology and definitions that need to be rectified, before take-back and MLC products become globally accepted.

Factor 5: Infrastructure

The infrastructure is of critical importance. Mr. D. Foley[46] of Xerox (Europe) Ltd. feels that companies could aim to operate a Just-in-time (JIT) storage and re-manufacturing system. This would make storage availability irrelevant, and probably re-manufacturing more profitable. Collection methods are dependent on supply (i.e. volume available) and client demand and are selected based on criteria such as cost and service to customer with very little promotion of collection systems taking place. Targets are currently being set by legislation to ensure that the collection rates will increase. The shape of the products can make collection logistics difficult. When the products are collected they may no longer be in the original box so stacking is difficult. For photocopiers and fax machines it is essential that they can be collected safely so as to improve the possibility of reuse. Some form of shelving, or air packing may need to be developed which has a minimal effect on the value to volume ratio. Xerox operates delivery and take-back from two types of tote that have eliminated the need for disposable packaging. Nortel designed a new reusable packaging system for shipping circuit boards that eliminates cardboard and foam waste (Kostecki, 1998). Securicor presently use specialized plastic crates for deliveries of some company's products that are then returned

[46] Contact details for Mr. Foley are given in Appendix A.

to the company for reuse. This eliminates the responsibility of disposal while also offering the possibility of being used for collection. For the collection logistics to be cost effective, space needs to be used efficiently. The current collection and delivery systems could be adequate if the material flow of products, components and materials is controlled, i.e. constant flow of material in and out of factory and suppliers. The three collection options outlined in the ECTEL study, No 1, 2 and 3 in Table 5-39 were also identified in this study along with the same funding options. Finally, some interesting issues arise with globalization, i.e. if the products components are sourced in low cost labor countries, the product is then manufactured in another country, and sold in a developed country, where should the responsibility for remanufacture lie?

Table 5-39 EOL Collection Options

No.	Collection Option
1	Through existing waste collection infrastructure, i.e. via the local authorities or municipalities.
2	Through obliging retailers to accept products.
3	Manufacturers collect from the municipalities, and undertake any subsequent sorting and recycling.
4	Manufacturers/dealers accept the products from users. Lease agreements would make collection easier as the manufacturers/dealers have control over the machines. The collection could be linked with the delivery of new machines, as the infrastructure is already in place, i.e. reverse distribution, thus ensuring the transport vehicles are always full.
5	Through encouraging customers to return used products, by offering a reduction when purchasing new ones.
6	Manufacturers set up their own collection systems for products and packaging.
7	Collection systems using 3rd party collection agencies, possibly in partnership with manufacturers.

Factor 6: Stakeholder Co-operation

All of the participants felt that all stakeholders need to be accountable and that closed loop co-operation between manufacturers, users, suppliers, EOL asset management companies, and other stakeholders was essential for successful take-back and a MLC industry. They felt that there was considerable scope for input from all the members of a supply chain into the design stage. EOL asset management companies could provide some essential information at the design stage regarding recovery options, and issues such as sorting, shredding, and recycling. For example, some dealers required more clarification on the reusability of certain photocopier drums. This could involve the manufacturer completing an ECD analysis, in consultation with the dealers and EOL asset management companies. Through co-operation and collaboration asset management companies could eventually offer full EOL solutions. Nortel has a reclamation operation that provides their divisions and customers with a full range of asset disposal and recycling services. Managing EOL electronic equipment at Hewlett Packard has provided multiple business opportunities from improved customer service and sourcing of spare parts to new revenue streams (Kostecki, 1998). Also, if manufacturers and their suppliers were prepared to buy back second-hand materials and components it would create secondary market for the EOL asset management companies. Suppliers to Xerox have accepted the task of creating the infrastructure to deliver parts in waste free returnable totes, accepting returned parts for remanufacture and reuse, and recycling any material determined to be at its EOL (deJong *et al*, 1999). Measures are required for transmitting information up and down the product chain. In the dealer survey, most of the participants were unaware of resource recovery methods and EOL asset management companies and unfamiliar with requirements of the take-back legislation. They expressed a willingness to co-operate with other key stakeholders. The participants also felt that the supply chain will become a key driving force and was critical for development of the re-manufacturing business. If the large manufacturers develop environmental systems, suppliers and sub-contractors will follow. Individual suppliers of electronic equipment are being requested by their customers to indicate their EOL take-back policy. More and more companies will follow the example of proactive manufacturers, such as Ford, and begin to incorporate recycled materials into new designs thus creating a greater demand for recovered materials. This will result in greatly improved material flows. Cross-industrial groups such as the Industry Council for Electronic Recycling (ICER), that draws together a range of stakeholders from material suppliers to EOL asset managers, will be key to the success of take-back initiatives. Through ICER, the U.K. industry works closely with government to ensure legislation is developed that leads to real environmental benefits.

5.2.7.5 Summary of Survey K

This survey of the established OA MLC industry was undertaken to assist in the development of the ECD methodology. Information was gathered on EOL asset management approaches, collection systems, and demand for recovered product, re-manufacturing processes and future forecasts through consulting a range of key stakeholders. Six key influencing factors were established which could determine the success and/or failure of photocopiers and fax machines in terms of a MLC. These principles can be integrated into a generic framework using the matrix-based approach for future application on other electromechanical products. A number of additional reasons why products reach EOL were also identified. These are given in Table 5-40.

Table 5-40 Additional Reasons for Shorter Product Lives

No.	Reason
1	Social pressure, for example, customers demanding new styles, shapes and colors to 'stay in fashion'.
2	Failure to fulfill original need or end of useful life, for example, children's pram no longer required as all children have grown up.
3	Legislation, for example, new legislation highlights negative impacts of products and customers phase out usage.
4	Products are intentionally designed for applications that mean a very short life, for example, packaging and disposable blades. Some products are perceived as having short-term lives, a 'throwaway image'.
5	Supply of parts, for example, a manufacturer stops producing spare parts so the product becomes obsolete.

5.2.8 Summary of Electromechanical Product Surveys

The surveys achieved their aims producing a 'body of knowledge' from a range of stakeholder groupings for electromechanical products. As with the study of PCs, in terms of identifying and weighting the 'top 5' environmental criteria, the views and opinions of ECD experts were found to be different. The requirement and environmental categories were re-verified by all participants. Thus, the matrix approach outlined in the study of PCs can be applied. For the closed-end surveys only the environmental categories were given to participants for confirmation and weighting. The environmental categories identified were verified in all of the closed-end surveys. Ranges of preferences concerning the importance of the environmental categories were evident from the participants, Figure 5-50. A number of significant variations were evident on the average weightings for all participants in 'Surveys E, F and G' thus indicating it may be difficult to produce a series of global weightings. These profiles of the average EFGH and average EFG are given in Figure 5-51.

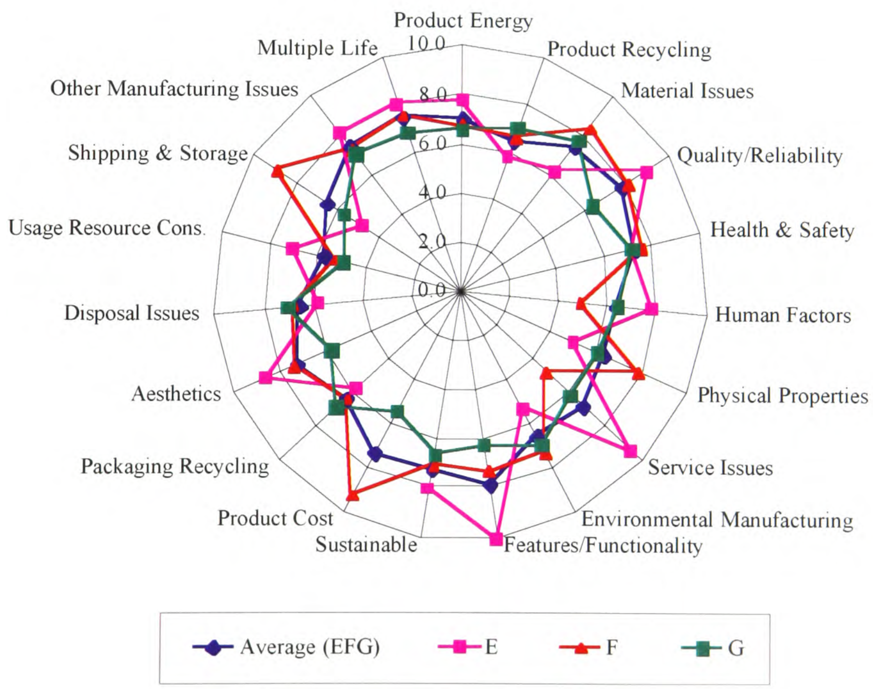

Figure 5-50 Average Weighting Profiles for Surveys E, F and G

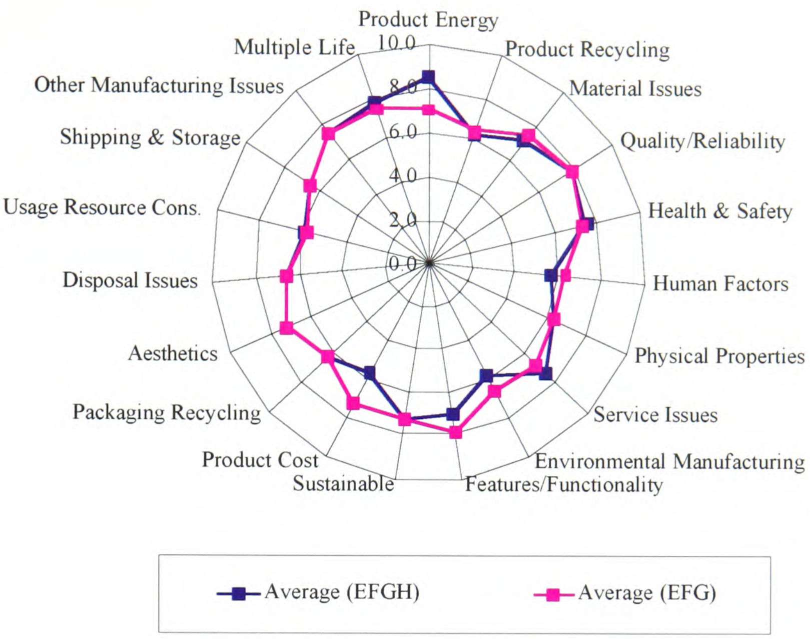

Figure 5-51 Average Weighting Profiles for EFGH and EFG

Taking the average weighting the top category for each survey are given in Table 5-41.

Table 5-41 Top Environmental Categories – Surveys E to H

Survey E	Survey F	Survey G	Survey H
Features/Functionality	Product Cost	Material Issues	Product Energy

Weightings EFGH can be applied in the approach outlined previously to develop environmentally conscious electromechanical products in terms of stakeholder preference[47]. Including the weightings in Table 5-8 could differentiate between stakeholder groupings. The ECD measure of a SLC product could be established through using Equation 5-1. Again this equation could be further expanded through treating different stakeholders within the broad

[47] These would include the average weighting from surveys E, F and G and the consensus weighting from H.

stakeholder groupings separately, i.e. having independent designer weightings. Finally the ECD category checklist was further developed based on the results from 'Survey E'.

A focus group was carried out to get ECD experts to verify and weight the environmental categories and examine the concept of involving key stakeholders in the ECD process. The main findings of the focus group are summarized in Section 5.2.5.7. A 'body of knowledge' was gathered from a range of stakeholder groupings, for EOL asset management of a range of electromechanical products. The results from the earlier study of the computer keyboard were found to be generic to a range of electromechanical products. The key factors and principles of a MLC industry were established for application to other electromechanical products through a generic framework.

5.2.9 Conclusions from Electromechanical Product Surveys

The study achieved its aims:

- Key requirements and environmental considerations for a range of electromechanical products were identified and grouped into a list of categories
- Relative weightings were provided, focusing on the environmental categories
- The concept of involving key stakeholders in the ECD process was examined. Information was gathered on the general views of participants on a range of issues, along with making some general predictions on the next 10 years (to 2009)
- EOL and MLC issues were examined for a range of products

A matrix-based approach can be applied for integrating this 'body of knowledge' into an abridged ECD process. The approach considers the views of a range of stakeholders and examines MLC options. The MLC factors, EOL routes, life spans, EOL reasons and other generic guidelines can be used to assist the LCT in deciding a life cycle strategy for a product. The next stage focuses on gathering a 'body of knowledge' and developing the methodology for packaging.

5.3 Packaging

This section involves using a survey of trainee product designers to gather category weightings for application in a matrix-based approach for packaging. It also tests the effectiveness of one ECD improvement approach in a case study of television packaging. Details of 'Survey L' and 'Case Study 3' are outlined in Table 3-5 and Table 3-6 respectively. A simplified research approach is given in Figure 5-52.

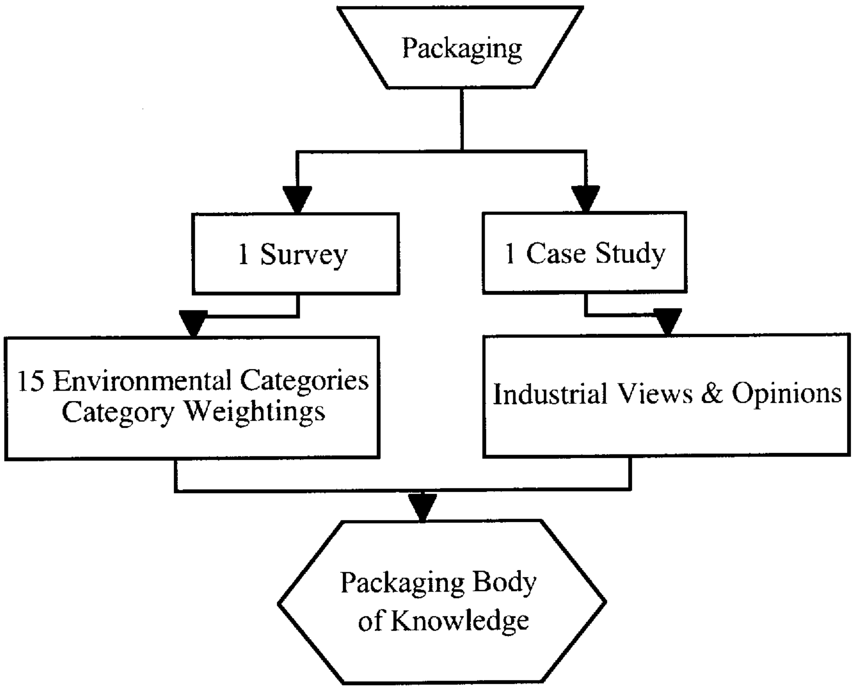

Figure 5-52 Simplified Research Approach for Packaging

5.3.1 Survey L: Trainee Product Designers / Consumer Packaging

This phase involved getting a group of trainee product designers to confirm and weight the list of key environmental categories identified in the product studies, using a closed-ended questionnaire. The product group selected was consumer packaging. The primary aim of this phase was to confirm the environmental categories for consumer packaging along with carrying out some weighting of their relative importance. The closed-ended questionnaire (Appendix A) was presented to the group. Participants were asked to confirm the key environmental categories before weighting them. Individually the participants had previously carried out a six-week ECD analysis and improvement study of the packaging using a range of abridged techniques including checklists, strategies, matrices and profiles. The students were encouraged to use a format similar to that outlined in Figure 5-15 and Figure 5-55. From the study they developed environmentally conscious concepts. Items selected for analysis included packaging for PCs, food, cosmetics and stationary.

5.3.1.1 Confirmation and Weighting of Environmental Categories

All 9 of the participants verified 15 of the 19 environmental categories. They felt that ‘product energy’, ‘product recycling’, ‘service issues’ and ‘usage resource consumption’ were not applicable. ‘Product cost’ was changed to ‘packaging cost’. No additional categories were suggested. The categories were weighted using the scale in Table 5-4. The ‘average weightings’ are profiled in Figure 5-53 with ‘material issues’, weighted ‘8.6’, being the top category.

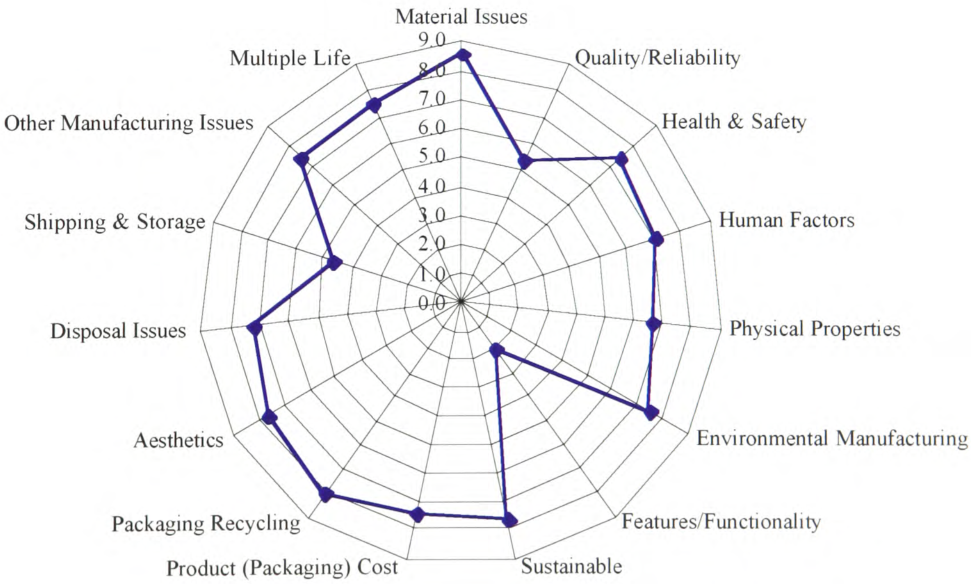

Figure 5-53 Average Weighting Profile for Consumer Packaging (Survey L)

5.3.1.2 Conclusions from Survey L

Using a closed-end approach, a list of environmental categories and a series of weightings have been identified for consumer packaging based on one stakeholder group, 'designers'.

5.3.2 Case Study 3 – Television Packaging

This phase involved testing the viability and productiveness of an ECD improvement approach on the packaging for a standard 14" television. The data gathering and analysis approach (Figure 5-15) had been successfully applied in the first two case studies. These studies involved incremental and radical improvement but they lacked a formalized structure. This case study was carried out to test a formalized improvement approach in an industrial environment. The approach was customized to meet the needs of the company; being carried out over a period of three days based on site in Panasonic. The study resulted in verification of the approach, with a wide range of environmentally conscious ideas for packaging conceived. The study also produced a 'body of knowledge' for packaging.

5.3.2.1 The Company

Panasonic, a division of the Matsushita Corporation, was selected for the study. Based in Cardiff, U.K., this company was established in 1974 and began production of color televisions two years later. All products developed by the corporation must pass their stringent LCA procedure while all their manufacturing facilities are certified to ISO 14001. Increased legislation, cost (transport, disposal and materials) and market image has ensured that packaging is at the forefront of environmental improvements. Focusing on these key areas, the author subsequently drafted a proposal on the benefits to the company from participating in the case study. Upon agreement of the proposal, Panasonic assigned a liaison person who was the environmental champion for packaging issues, Mr. I. Karttunen (Design Engineer). The liaison person was an educated designer with no environment-related qualifications, but who had specific packaging knowledge. His role was to provide a direct link to the company, and to provide access to packaging, supplier information and packaging samples.

5.3.2.2 The Product – Television Packaging

Packaging is perceived as having a short-term life cycle although in reality it should not always be obsolete when it reaches its first EOL. This disposable image change ('Reason No. 4', Table 5-40) needs to change. Rather than intentionally designing the packaging for a SLC, consideration on how the life span can be extended or how the packaging can be recovered more efficiently is needed. Currently Panasonic uses expanded polystyrene (EPS) cushions with the help of a cardboard carton to protect the televisions against different environmental conditions caused by transportation and storage. The material costs are estimated at between 50-60% of the overall packaging costs. The main areas of the television that need to be supported are the front corners and edges near to them on the cabinet. The cathode-ray tube (CRT) is rigid and the heaviest component of a television, and is attached with four screws to the front inner face of the cabinet. The parts that usually fail in drop testing are the cabinet and back covers, which are made from injection-molded polystyrene, and make a contribution to the impact absorption.

EPS Cushions

Panasonic had previously established that EPS was the best currently available material for packaging televisions. It is recyclable, non-toxic, and economical and it has all the desirable mechanical properties. These include its shock absorption characteristics, ease of molding, resistance to moisture, durability and low weight. The key drawback of EPS is that it is plastic: made of 2% polystyrene and 98% air. Reuse of EPS products is usually non-profitable because of the low initial cost of the EPS products. It is economically profitable to recycle EPS through avoiding landfill costs and payments to recycling organizations. EPS is easy to recognize and therefore also easy to segregate from other materials before it enters the waste stream. Contamination is not a major issue because EPS is predominantly used for packaging clean goods. Recycling starts usually with compacting of the EPS to about 1/40 of its original volume. This makes handling of EPS more economical and practical. There are several different applications for recycled EPS including products like plant pots, hangers, and video and audio tape cassettes, Figure 5-54.

Cardboard Cartons

The cost of cardboard is about 10% higher than the cost of EPS. The cartons can be recycled and reused as a raw material in other manufacturing processes. Because repeated processing shortens and weakens the fibers of the material, it can be recycled approximately 4 - 6 times. After their recycled life, these fibers are usually used in incinerators to produce energy or as a land application for agriculture.

The main stages in the current life cycle from the packaging of the television through to the various EOL options are shown in Figure 5-54.

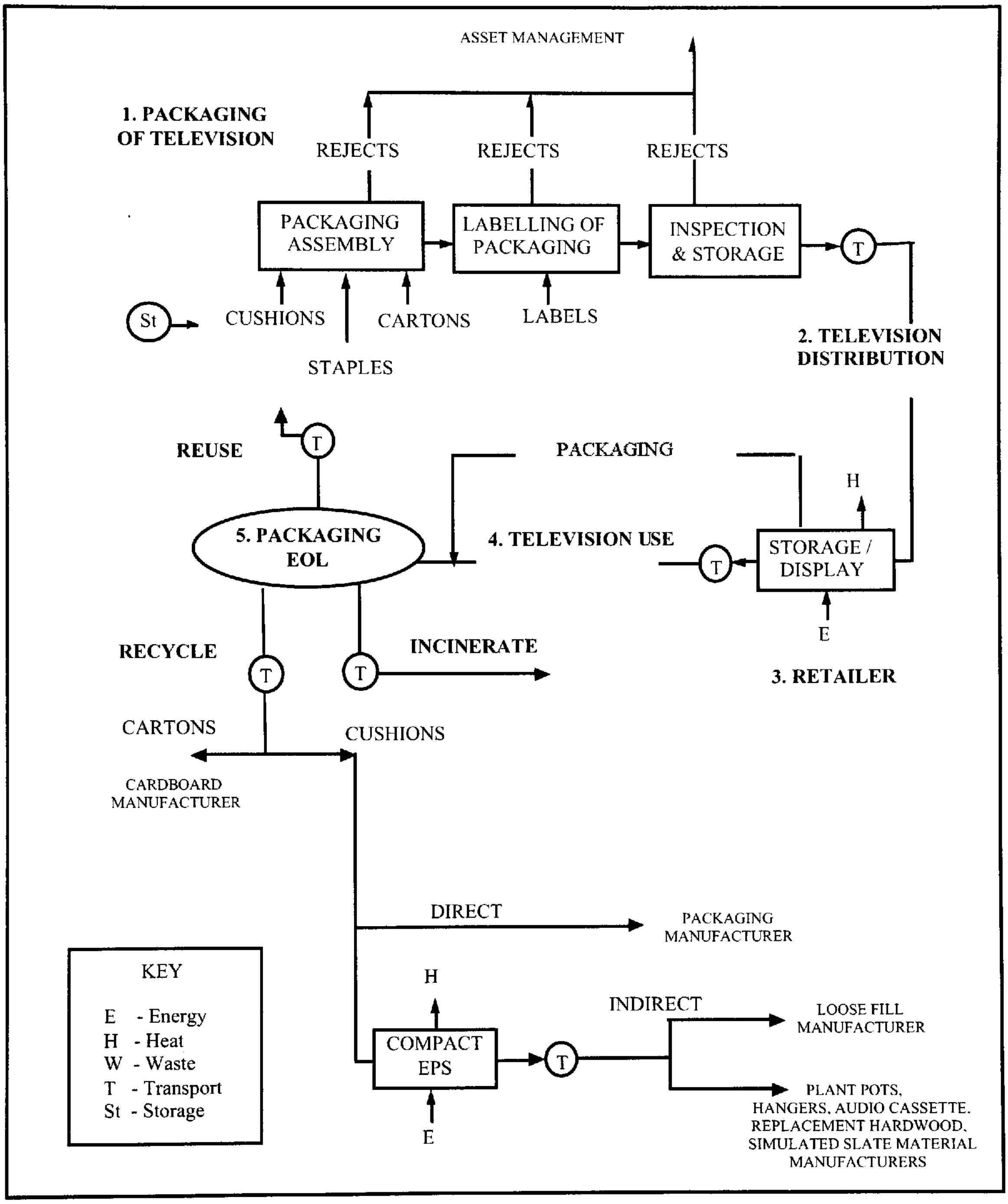

Figure 5-54 Current Packaging Life Cycle

Printing

Printing is a minor expense in the total packaging cost but reducing the amount of printed area lowers this cost and reduces the chemicals needed to wash the prints out of the recycled paper. A reduced print area can also give an environmentally friendly image, although televisions in some countries are displayed in their packaging, and printing is an important way of communicating with the customer.

5.3.2.3 Re-Design Approach

Panasonic required a new approach to developing environmentally conscious product and packaging concepts. The chosen approach (Figure 5-55) involved three key stages: 'Preparation', 'Idea Generation' and 'Idea Selection'. In parallel, Panasonic initiated a number of other studies to establish if they could make the design of the packaging less complicated and save resources. These included an examination of the current packaging testing procedure, and transportation and storage requirements. This information would also be valuable when making decisions on any new concepts generated, or on any new packaging materials identified. Along with focusing on the packaging, it is important to examine the entire environment the package is working in, look at the whole process of getting a package and product out of the factory (Jedlicka, 2000).

Stage 1: Preparation

The preparation involved clarifying the background and key requirements for television packaging, with the author guiding three key members of the companies CFT: the environmental affairs manager, mechanical design manager and the liaison person. 'Mind Mapping' was found to be especially useful in reducing the problem down to its basic elements[48]. This technique is reviewed in detail in Buzan and Buzan (1990). An abridged ECD study was not undertaken at this stage.

[48] The author had tested 'mind mapping' in numerous creativity and improvement workshops.

Stage 2: Idea Generation

Numerous techniques are available to facilitate idea generation (Plsek, 1998, Provost and Sproul, 1996). The approach used the following creative thinking tools that are useful for both incremental and radical improvement: 'Random Word', 'Empathy', 'Analogy' and 'PO'. Idea generation was supported through integrating environmental mind-sets into these traditional creative tools. The 'random word' technique was reviewed in Section 5.1.7.2. 'Empathy' is a method of idea development actuated by considering a personal involvement in the project (Svensson, 1976). The essential characteristic of this approach is to imagine that you are part of the product or packaging to be designed. Analogy involves examining other situations or devices that have features in common with the problem in hand (Svensson, 1976). The 'PO' technique, developed by De Bono, involves defining the usual way of doing something and then producing a statement of thought that negates that which is taken for granted. The result is a deliberately provocative statement that is illogical and/or impossible. The technique is useful in producing totally new perceptions of a situation and for generating radical change (Provost and Sproul, 1996). The idea generation involved using a group of 12 trainee product designers who had participated in a number of pilot studies[49] and were selected to ensure unconstrained thinking. The 3-hour session was divided into a number of key stages, beginning with the liaison person and environmental affairs manager giving a 20-minute overview of the background and key requirements. The participants were then divided into 4 groups of 3 and assigned a creative technique to apply, with the brief to generate as many ideas as possible for environmentally conscious packaging concepts, in a 40-minute timeframe. Requirements such as cost, ease of manufacture, and reliability were not considered at this stage. They were encouraged to integrate an environmental mind-set into the techniques through the use of words and themes from nature, and through considering strategies such as reduction, reuse, and recycling. Sample televisions without the packaging were supplied. Each group was allotted a

[49] The approach had been piloted in a number of workshops at the UOG where the trainee product designers were undertaking a 'Product Design' degree course.

5-minute time slot to present their ideas for initial clustering. The participants were then given a 40-minute tour of the production facility taking in the packaging, storage and assembly areas. This included an overview of the packaging materials and printing. Samples of the current packaging were made available during a second 40-minute creativity session, with each group assigned a different technique to apply. Again requirements such as cost, ease of manufacture and reliability were not considered. After the idea generation each group was given a 5-minute time slot to present their ideas for final clustering. A range of ideas was inspired from the creativity session. These ideas were clustered together and discussed in more depth, with some additional concepts added.

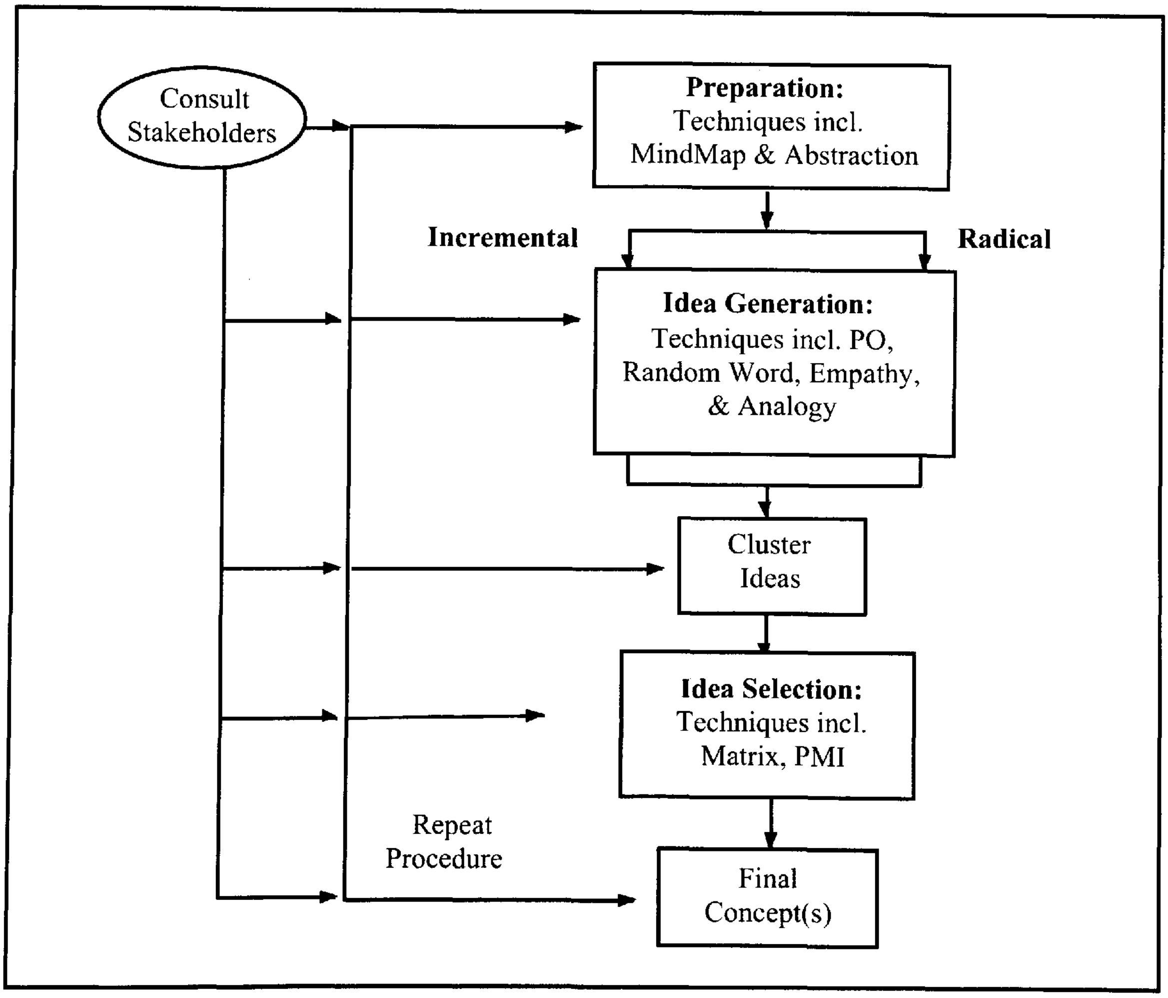

Figure 5-55 Iterative ECD Improvement Approach

Stage 3: Idea Selection

Following both of the creative sessions the ideas were clustered together, with the initial decision making and filtering of ideas undertaken by the liaison person, under the guidance of the author. The final set of ideas and concepts were then presented to the CFT and external stakeholders for evaluation and selection[50]. The liaison person was assigned responsibility for getting input from key stakeholders such as sub-contractors, suppliers and EOL asset managers. The chosen concept needed to incorporate key requirements such as cost, safety, and ease of manufacture, and reliability, under drop testing and shipping and storage. The results from the studies of the current packaging testing procedure and transportation and storage requirements were also considered. For idea or concept selection, 'Comparison Matrices' have been found to be especially effective[51]. The matrix technique is outlined in Pugh (1991).

5.3.2.4 Re-design Results

Examples of how each of the idea generation techniques were applied are provided in the following sections, along with the three 'new' concepts, which were deemed to be viable options.

'Random Word' Applied to Television Packaging

A number of random words were selected from nature. One idea generated involved the use of biodegradable materials, which is something Panasonic had begun to consider. There are a wide variety of EPS substitutes being developed from materials such as starch. STOROpack (Germany) have a product, termed 'Enviromold', which uses natural starch as a possible replacement for EPS. The scenario using starch-based foam would be quite similar to the

[50] The author was not involved in the final concept selection
[51] The author had tested 'comparison matrices' in numerous creativity and improvement workshops.

current situation where most of the material and all of the energy needed for manufacturing the EPS cushions is lost. Unlike EPS, starch-based foams dissolve easily in water and are biodegradable; thus there is no legislative recycling obligation. These characteristics make the disposal of these materials easy, simple, and environmentally friendly. The performance of starch based foam during the packaging life needs to be investigated. Another idea generated involved the development of packaging with a secondary function. This would ensure a full utilization of the packaging, creating a MLC. It leads to three possible levels of function for the first EOL stage of the packaging, Table 5-42. The packaging could be reused, have a secondary application related to the original application, or have an unrelated tertiary application. The main disadvantages would be that stakeholders needs are different, both the packaging and television would need protection, and it would most likely to be a more expensive system than the current.

Table 5-42 EOL Levels of Function

Level	Function	Applications
1	As per original	Packaging
2	Related to original	Television ancillary device: stand, cover, etc.
3	Unrelated to original	Board game, dolls house, children play house, furniture, waste box, etc.

'Empathy' Applied to Television Packaging

The participants followed two approaches of personal involvement: firstly imagining they were the television, and then imagining they were the packaging. Some of the ideas generated are presented in Figure 5-56. Using the cardboard as a cushioning material would create a mono-material packaging system that would be easily and conveniently recyclable at EOL.

'Analogy' Applied to Television Packaging

One idea generated involved the use of air packaging. The Delft University of Technology has since investigated the use of air packaging on behalf of Sony, one of Panasonic's main competitors. The study found air packaging to be more environmentally conscious through reduction, reuse and recycling (Otto, 1998). A reusable packaging system saves both the materials and energy needed for manufacture. Great Western Packaging Company have developed a patented concept known as 'Pneumatic Cushion Packaging', termed the 'Q-CELL', that works on the basis of aiming to control the flow of air around a network of inflated cushion cells, placed around a product. After use the packaging can be deflated to a flat state and easily returned back to the supplier. The benefits of this new design include an extended life cycle, better protection, reduced use of material, easy of reuse and recycling, and reduced shipping costs.

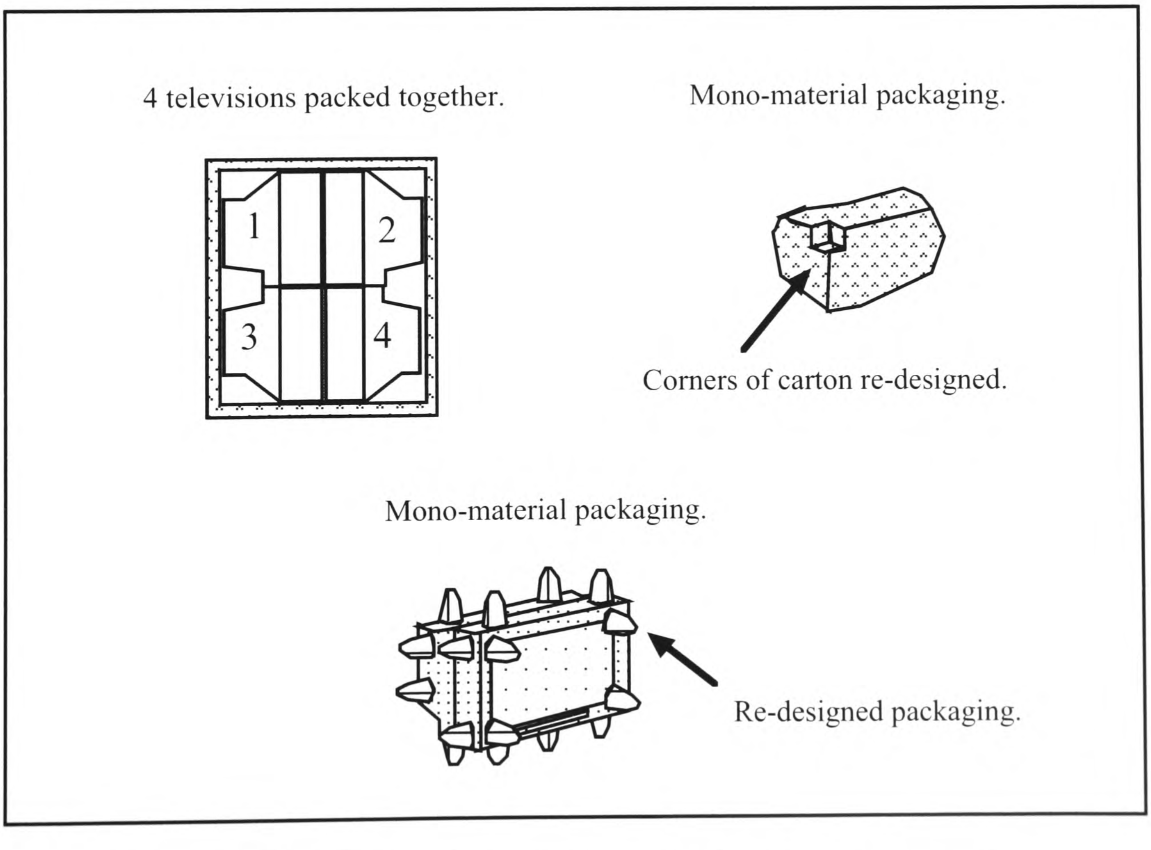

Figure 5-56 Application of the 'Empathy' technique (Packaging)

'PO' Applied to Television Packaging

The students identified numerous variations to the existing concepts using statements such as: 'PO' Televisions do not need packaging. One idea generated consisted of using the television exterior as the packaging. This would eliminate the use of EPS and cardboard but it creates a number of interesting design problems that would require further detailed investigation. The concept of reducing the packaging, and picking up the print information themes through the display environment in places such as shopping centers is another option (Jedlicka, 2000).

Packaging Concepts

Some concepts were found to be applicable only to certain models because factors such as the weight and size create problems using certain materials. The three concepts that emerged from using these techniques, that were also considered to be viable options by the company are included in Table 5-43. Other ideas could be derived from various combinations of these.

Table 5-43 Viable Packaging Concepts

No	Concept	Comments
1	Reusable air cushioning system returnable by post.	The technology is there to support this approach (as Sony has shown with their disposable air cushions study). It required changes into the closing method of the carton - glue or tape instead of staples.
2	Molded starch foam cushions.	The starch foam does not perform as well as EPS. As technology improves, this may not be an issue. Also cost may drop with larger quantities and improved manufacturing methods. The raw material was cheap but the large proportion of early production was still manual thus resulting in high labor costs. The technology was still in its infancy.
3	Cardboard cushions with paper honeycomb inserts	The cost, impact recovery and reliability were of potential concern with this option.

5.3.2.5 Conclusions from Case Study 3

Due to reasons such as cost, market image, and pressures from legislative bodies to reduce, reuse and recycle, Panasonic carried out the ECD improvement case study. The ECD emphasis was on both incremental and radical improvements to given design elements. The study was limited in that a detailed data gathering and analysis was not undertaken prior to the improvement session. Under these constraints, the iterative approach chosen provided a quick, yet effective method of generating a range of possible improvement ideas. The formalized structure for applying creative thinking techniques forced the designers to generate innovative and radical solutions. The case study shows how such a cost-effective approach, even if completed on a small scale, can provide useful and practical results, thereby demonstrating that there is a way forward in ECD improvement for SMEs without having to commit too many resources. The full backing of management was vital to the induction of ECD improvement in the company through the allowance of time and resources for employees to participate in the studies. Through the assistance of a liaison person it was possible to complete the study in a short time frame. The importance of stakeholder participation in ECD was highlighted at the concept selection stage, where information from external stakeholders such as suppliers and EOL asset managers was critical to the decision process. The study was used as a platform for incorporating ECD improvement into the Panasonic design process with the ideas being used as 'concept demonstrators' to identify long-term solutions. The study also identified three EOL levels of function and a typical life cycle path for consumer packaging. These will assist in the development of the ECD methodology.

Feedback

The feedback has been extremely positive. Panasonic was extremely pleased with the outcomes, finding it an extremely worthwhile and beneficial exercise with a number of packaging concepts generated. The ECD improvement approach is a useful addition to their design toolbox. In all the concepts generated a common feature was that the cost was the major setback. Margins within television manufacturing are very tight, so it is difficult to justify a solution that would increase the total cost. Further examination concentrated on two solutions:

molded starch foam cushions, and cardboard cushions with paper honeycomb inserts. The students also found the exercise helpful, giving them a practical insight to the real problems facing companies, while allowing them to gain some practical industrial experience. Variations of this approach have since been successfully applied in a number of other workshops.

5.3.3 Summary of Packaging Section

A list of environmental categories and a series of weightings have been established for consumer packaging. Only one stakeholder group, namely 'designers', participated in the survey. To obtain a range of preferences concerning the importance of the environmental categories other stakeholder groups should be consulted. The 'average weighting' from the survey can be applied in a matrix approach, similar to that outlined in previous sections, to develop environmentally conscious packaging in terms of stakeholder preference. Thus, the ECD measure of a SLC package could be obtained through using a similar equation to 'Equation 5-1'. Again, this equation could be further expanded through treating different stakeholders within the broad stakeholder groupings separately. Finally, to facilitate the scoring process the ECD category checklist can be modified to cover the packaging categories only. It can be used to provide guidance to the LCT when scoring a particular package. The matrix approach could be used to assess the new concepts that arose from the case study, to ensure the environmental impact is reduced at each stage of the life cycle. The typical packaging life cycle, and EOL levels of function, can be used in conjunction with the EOL and MLC data collected from the previous surveys, to assist the LCT in deciding a life cycle strategy for a product or packaging. The formalized ECD improvement approach chosen provided a quick, yet effective method of generating a range of possible improvement ideas. The importance of stakeholder participation in ECD was highlighted at the concept selection stage.

5.3.4 Conclusions from Packaging Section

The study achieved its aims through gathering category weightings for application in a matrix based approach for packaging, and testing the effectiveness of one ECD improvement approach in a case study of television packaging. The next stage focuses on developing a new ECD methodology for application to a range of electromechanical products, using the 'body of knowledge' gathered through the surveys and case studies.

5.4 Varying Factors

In weighting the categories by the range of stakeholder groupings it is becoming clear that it is very difficult to produce global figures for all electromechanical products. A number of significant variations were evident on the average weightings for all participants in 'Surveys E, F and G'. Using this approach the validity of summing the results for global application is questionable[52]. The process is dynamic, making it difficult to develop an approach with absolute numbers, as there are numerous other influences that can affect the opinions of the participants, including legislation, media and advances in technology. Some of the key influences on personal opinion, based on discussions with 16 ECD experts were outlined previously in Table 5-35. These 10 key factors highlighted the possible variance in categories and weightings for a range of products. A number of other varying factors was noted during the surveys that could greatly influence the categories, weightings and other results, Table 5-44.

[52] There are no similar surveys to compare the outcomes to.

Table 5-44 Varying Factors

No.	Factor
1	Product
2	Profession
3	Industry
4	Type of Weighting
5	Method of Weighting
6	Company Focus/Policy
7	Respondent Background
8	Environmental Expertise
9	Expertise in using Design Techniques

Product

Familiarity with the product(s) being analyzed is an important factor. In the case of PCs there are notable differences in 'energy' and 'usage resource consumption' between products such as keyboards and printers thus you would expect their respective weightings for these categories to be different.

Profession

Different professions may consider certain categories to be more important. For example, in 'Survey B' an electronic designer gave a weighting of '6' to 'aesthetics' while a product designer gave it a weighting of '10'.

Industry

Different electromechanical product industries may consider certain categories to be more important. This is demonstrated in using the results from 'Survey B' and 'Survey F', Table 5-45.

Table 5-45 Industry Weighting Variations (PCs and Televisions/Microwave Ovens)

Environmental Category	PCs	Televisions / Microwave Ovens
Human Factors	7.3	4.8
Service Issues	6.9	4.7
Shipping & Storage	6.4	9

Type of Weighting

In 'Survey B' a significant difference was established between industrial participant 'ideal' and 'actual' weightings.

Method of Weighting

There are numerous methods of weighting the categories. Clear variations were evident between 'Weighting Method A' and the 'average weighting' in 'Survey A' and 'Survey E' respectively.

Company Focus/Policy

If the company is currently focusing on certain environmental concerns, then the weightings for these may be vary depending on the how the employees have been influenced. Prior to when 'Survey B' was undertaken, Alps had been predominantly directing its attention towards the environmental effects of manufacturing and thus the 'top 5' categories included both 'environmental manufacturing' and 'other manufacturing issues'.

Respondent Background

The outcomes could vary depending on the background of the participants. If they are living in an area of high pollution or water shortages they may be more likely to place emphasis on 'environmental manufacturing' or 'usage resource consumption'. They could weight the categories as a professional, as an individual user, as a family person, or even as a member of the community. Some of the participants responded as users and not according to stakeholder role. For example, in 'Survey B', a participant from the service area weighted 'product cost' more important than 'service'. Some encountered a 'conflict' between their professional role and their role as product user. One participant in 'Survey B' was asked to answer firstly as a user, and then as an environmentalist. Significantly different profiles are evident, Figure 5-57. As might be expected, the environmentalist placed higher emphasis on categories such as 'disposal' and 'product recycling'.

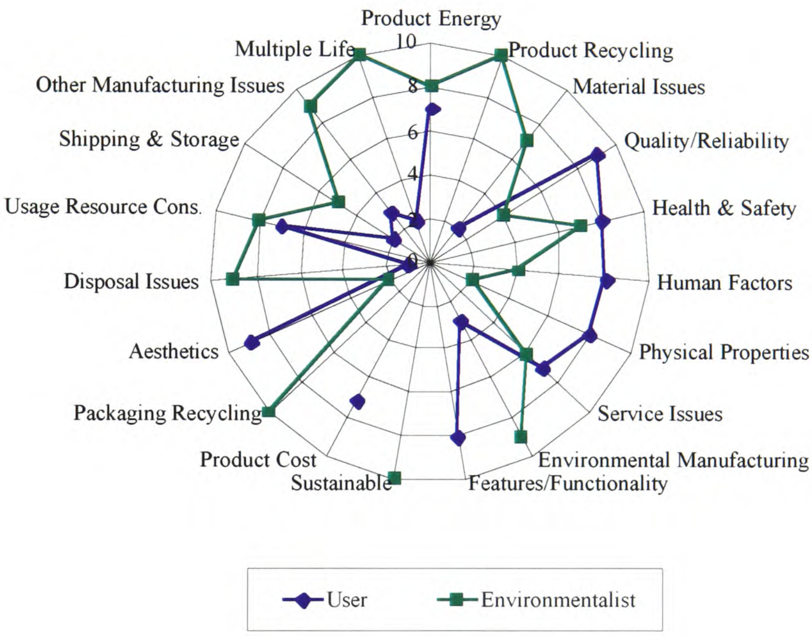

Figure 5-57 Variations between responding as a 'User' and 'Environmentalist'

Environmental Expertise

The outcomes could vary depending on the participant's level of environmental expertise. If a participant is knowledgeable of various environmental hazards, they may be inclined to weight any related categories higher.

Expertise in using Design Techniques

One factor that could have influenced the improvement case study, was the level of expertise and experience in using the creativity tools.

5.5 Final Conclusions of Main Study

The main study achieved its aims, gathering a 'body of knowledge' from a range of stakeholders in surveys and industrial case studies of PCs, electromechanical products and packaging. It included an in-depth look at the EOL asset management of electromechanical products and varying factors that could affect the results. The next stage of the research focuses on developing a new ECD methodology to incorporate this 'body of knowledge'.

6 New ECD Approach

This chapter outlines the new ECD approach and tests it on two product studies, using independent assessors.

6.1 Overview

It is clear that new ECD approaches and techniques will have to be able to adapt and interface effectively with various stakeholders in the design and development process and over the life cycle of a product, to ensure that both SLC and MLC issues are considered. The techniques need to be able to assist in selecting a life cycle strategy, analyzing designs and suggesting possible improvement methods. The research has examined the role of stakeholders through a series of surveys and industrial case studies. A 'body of knowledge' (a set of criteria representative of stakeholder views and opinions) had been gathered from a range of stakeholders over the life cycle of a range of electromechanical products and their packaging. This 'body of knowledge' consists of the environmental criteria that stakeholders consider important in evaluating alternative designs. A list of 19 environmental categories has been identified that can be applied to a range of electromechanical products. These categories are linked to the key life cycle stages: manufacture, distribution, use, service and EOL asset management[53]. Some considerations identified are applicable to more than one of the environmental categories. For example, selecting the correct type of product labeling could be considered a 'materials issue' and a 'product recycling' issue. An ECD category checklist (Appendix B) was developed to assist in weighting and scoring these categories when evaluating electromechanical products and their packaging. The 'body of knowledge' also includes other factors and principles that stakeholders consider important in evaluating designs and selecting a suitable life cycle strategy. This includes generic guidelines, MLC factors, EOL routes, levels of function, and reasons why products reach obsolescence. These are reviewed

[53] Raw materials acquisition is included in the manufacture stage.

when deciding the life cycle strategy for the product and packaging. These tailor-made tools assist in defining environmental priorities and devising design rules. They also support other decision-making actions at various stages of the products life cycle. Unlike other abridged approaches, the 'body of knowledge' has been gathered from a range of stakeholders, the LCT, and not just internal CFT members.

A matrix based methodology for implementing this knowledge within an abridged approach was explored in the research. The methodology consisted primarily of a 'Life Cycle Strategy' worksheet, input-output flow diagrams, matrices, profiling, checklists, and improvement tools. It was used to analyze, score, and improve designs in three industrial case studies. These techniques were found to be very effective in the pursuit of environmental analysis and improvement. This section incorporates the 'body of knowledge' in the methodology, and examines how a company can successfully implement it in an abridged approach. The abridged approach is quick and easy to use, and of immediate value to the company. Traditional LCA takes too long to execute, is data-intensive, and the results are often difficult to interpret. Through consulting key stakeholders dissimilar environmental effects, such as recycling and disposal considerations, can be weighted against each other to clarify which product design is less harmful. This approach has the added advantage of being able to analyze traditional design requirements, such as quality and reliability, alongside environmental considerations, such as the energy consumption of the product. The new approach maintains the fundamental essence of traditional LCA, in analyzing the full life cycle, but due to its qualitative nature, it does not require collection of vast quantities of data. It includes a mechanism for incorporating stakeholder requirements and strategies in the process. The approach ensures that multi-criteria value judgements are not based on an individual assessor, but a group of stakeholders who participate in deciding the life cycle strategy, and weighting and scoring the categories. The data is generalized for a range of electromechanical products and the approach can be implemented as part of a GCE process.

6.2 Role of Stakeholders

Stakeholder participation and co-operation is key to the successful implementation of the abridged approach. The 'body of knowledge' and methodology was developed through consultation with key stakeholders and can be continually updated through further discussion. Key stakeholders decide the life cycle strategy, weight and score the environmental categories, and participate in developing the 'ideal' concept. The surveys and case studies were used to determine the assignment of stakeholders to certain stages within the approach. One person is assigned to co-ordinate the approach. Although this coordinator can individually make the required decisions, he or she is encouraged to work as part of an assessment team, the LCT. If stakeholders cannot take their place at the table, the coordinator should consult at least one stakeholder from each stakeholder grouping assigned. If they take the option to contact more than one stakeholder from each of the assigned stakeholder groupings, the assessment will take longer to complete. However, it may result in a more accurate reflection of stakeholder opinion, because in terms of weighting the key environmental criteria, the views and opinions of similar stakeholders were found to be different.

6.2.1 Weighting

There are a number of sections of the approach that were investigated to see if weightings could be applied to assist in setting priorities. These were the stakeholder groupings, life cycle stages, and categories. As the focus group participants expressed difficulty with the task of weighting stakeholders (Section 5.2.5), and there was some inconsistency in their selections, it was decided not to apply weightings to stakeholders. It was felt that the stakeholder weightings (Table 5-8) would be more suitable for guiding decisions on a regional, national or global scale, for example, banning the use of certain materials, or manufacturing processes. Here, the stakeholder groupings that were weighted highest could adopt the main roles in setting priorities: government, through legislation, and users, through opinion surveys. Stakeholders such as the government could be considered as 'generally applicable', with their views and opinions applying to a range of products. Selections from stakeholder groupings such as designers can be classified as 'specifically applicable' applying to one product or product family only. It was decided not to apply weightings to the life cycle stages although the LCT may decide to prioritize certain stages during the assessment. The focus group and industrial participants expressed difficulty with the task of weighting life cycle stages (Section 5.2.5), and again there was some inconsistency in their selections. The process of obtaining category weightings was dynamic, and it proved very difficult to develop a tool with absolute numbers. It was found that it is very difficult to arrive at global figures for all electromechanical products, thus the validity of a summed result for global application was found to be questionable. There are numerous other influences including legislation, changing attitudes of public due to media and other influences, and advances in design and technology that can affect the weighting process. There was also a substantial difference between some of the participants 'ideal' and 'actual' weightings. The stakeholder preference weightings were not found to be significantly different for PCs[54], so the average weighting from these studies could be applied directly in the assessment of PCs. The preference weightings for a range of electromechanical products had significant variations. Further research could involve categorization under areas such as product, profession, weighting type and level of environmental expertise. Other methods of devising the environmental category weightings were also considered. These include prioritizing through commonalties using links (Jones, 1980). The chosen approach recommends consulting assigned key stakeholders to decide on the weightings.

6.2.2 Overcoming Varying Factors

Factors that influence ECD now and that may do so in the next 10 years were established, as well as those that influence personal opinion (Table 5-35). These factors could cause a variance in the results. Therefore, it is recommended that they be reviewed as part of an initial training course, and again during the analysis stage, to ensure they do not adversely affect the

[54] The two exceptions to this are outlined in Section 5.1.5.

outcomes of the assessment. The coordinator can ensure that the other varying factors (Table 5-44) are accounted for through the following methods outlined in Table 6-1.

Table 6-1 Accounting for Varying Factors

No.	Factor	Approach
1	Product	Ensure all LCT members are familiar with the product(s) being analyzed
2	Profession	Ensure that the assigned stakeholders are consulted in the weighting and scoring of categories.
3	Industry	Ensure the assessment focuses on one industry.
4	Type of Weighting	Ensure that the LCT is consistent with the type of weighting, whether it is 'Ideal' or 'Actual' weightings.
5	Method of Weighting	Ensure the LCT is consistent with the method of weighting, i.e. mode, median or average.
6	Company Focus/Policy	Ensure the LCT is not overly biased towards certain environmental concerns.
7	Respondent Background	Monitor the background of the LCT to ensure the results are not biased.
8	Environmental Expertise	Monitor the level of environmental expertise of the LCT to ensure the results are not biased. Provide ongoing training courses to increase their expertise.
9	Expertise in using Design Techniques	Through providing training courses the coordinator will also ensure that there is a high level of expertise and experience in using the various analysis and improvement creativity techniques.

6.3 Multi-Stakeholder Abridged ECD Approach

The 'Multi-Stakeholder Abridged ECD Approach' was developed into a paper-based approach, for presentation in the form of a handbook. A person, who is familiar with the product being assessed, should coordinate the implementation of the approach. For example, an internal member of the LCT, such as a designer or the company's environmental champion. It is also possible for an independent external person to coordinate the assessment once they have sufficient knowledge of the product. This may require specific training. It is recommended that the coordinator, and where possible key internal and external members of the LCT, should undertake a short training course in ECD, focusing on the role of abridged techniques. This training should be carried out by an ECD expert and would be between 6 to 8 hours in duration[55]. This should be sufficient duration to gain a working familiarity with ECD and abridged approaches. After the training course, mentoring or one-to-one tutoring is seen as an ideal way of developing the coordinator's competency with the approach, and should be undertaken the first time that the assessment is implemented. This would ensure that the coordinator possesses a suitable level of environmental expertise to guide the other stakeholders in making the necessary decisions. The ECD approach is based on the analyze-report-prioritize-improve framework and involves a clearly defined step-by-step procedure, Figure 6-1. It is seen as a perfect mechanism for incorporating stakeholder requirements and strategies in the ECD process, with key LCT members, participating at predetermined stages. The approach involves the coordinator guiding some key internal members of the LCT, who take an active part in the full assessment, with external members represented through the coordinator[56]. The active participation of these internal members, marketing, materials, design, manufacturing, and management, at the table is dependent on constraints such as time and cost. The approach should be used for re-designing an existing electromechanical product and its packaging, or comparing alternative designs. It can also be used for designing novel versions, although it is tailored towards the former applications.

Five generic guidelines have been devised for ECD. These should be considered at the start of the assessment process, and are critical to its successful implementation. These are given in Table 6-2. The individual steps are then outlined in detail in the following sections. The LCT

[55] This duration is based on an undergraduate module for trainee product designers carried out at UOG. Details of the module are given in O' Connor (1998).

[56] External members may be invited to the 'table' at certain stages of the assessment.

whose members should, at a minimum, include representatives from marketing, materials, design, manufacturing and management should undertake these steps.

Table 6-2 Generic ECD Guidelines

No	Guideline
1	Introduce the ECD approach as early as possible in design process, preferably at the market innovation and concept design stage.
2	Integrate ECD at each stage of the design process and every level of the product, from material selection to manufacture and assembly through to EOL recycling.
3	Ensure a closed loop co-operation between all key stakeholder groups and make them aware that the impacts at each stage of the product life cycle affect the products overall environmental profile. These impacts include emissions, health and safety, resource use, waste and employee issues.
4	Consider the hierarchy of reduce, reuse, remanufacture, recycle, recovery of heat and safe disposal at all stages of the assessment.
5	Where appropriate, in terms of cost, time and required complexity, use other ECD techniques to increase the accuracy of the outcome or satisfy legislation requirements. These techniques could include Blue Angel criteria, guidelines from the WEEE directive or packaging directive, quantitative LCA or material selection techniques.

Step 1: Choose a Level of Analysis

There are three options: product, component and material[57]. The LCT decides which level to focus on. If the product level is selected, then the assessment focuses on the complete product and ignores the fate of individual components and materials. Likewise, if the component or material levels are selected, the assessment focuses on the selected component or material and ignores the fate of the remaining components or materials. The LCT should refer to the Bill of Materials (BOM) when making the selection.

[57] Packaging can be assessed through one of these levels.

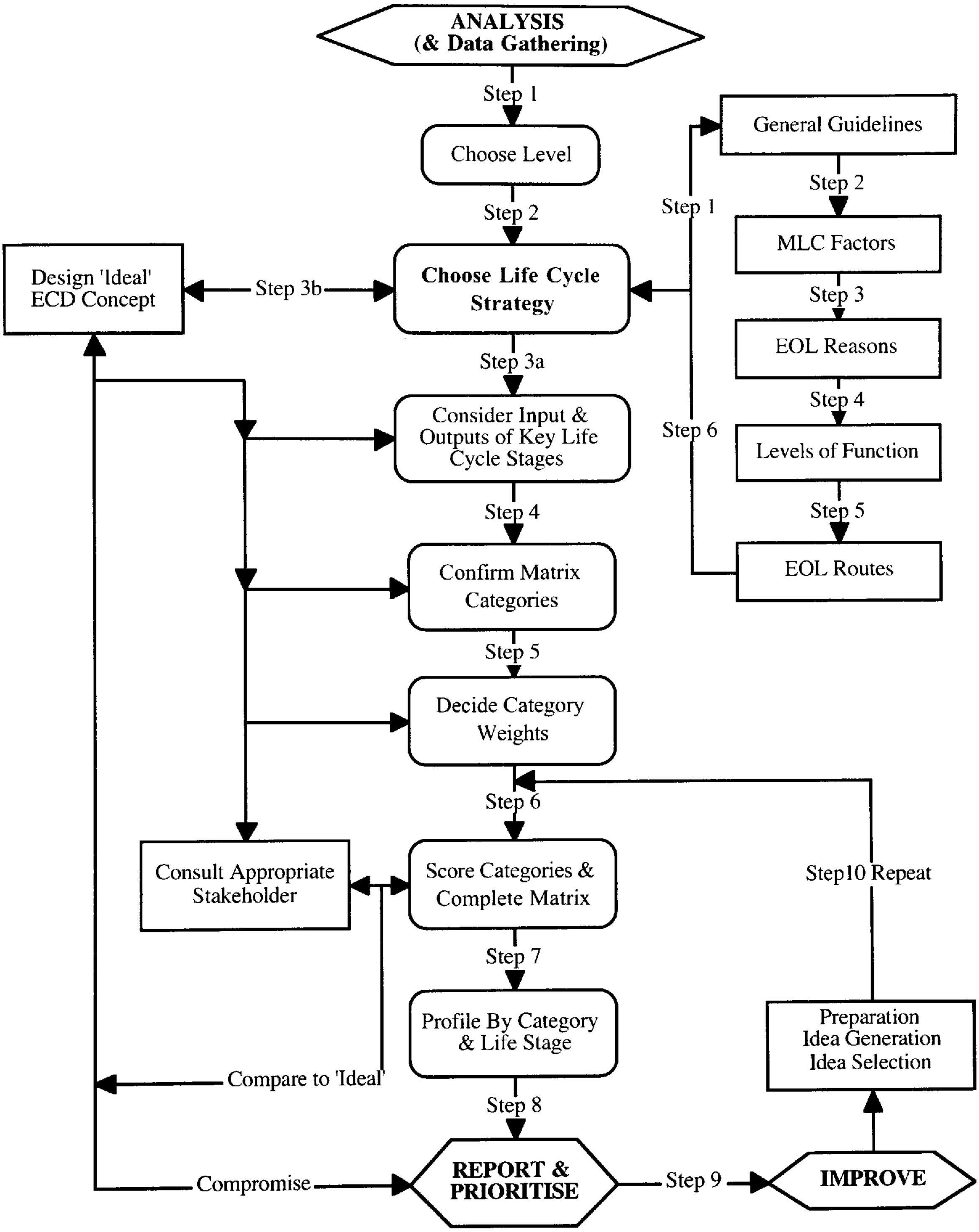

Figure 6-1 ECD Methodology Flow

Step 2: Choose a Life Cycle Strategy

Using the flow chart (Figure 6-1) and accompanying tailor-made guidelines (Section 6.3.1 and Appendix B) there are a number of options to select here. Decisions are made on the product life span, routes to apply, for example recycle or disposal, whether it is SLC or MLC, and whether the use level moves to secondary and tertiary levels[58]. The coordinator ensures that the views, knowledge and experiences of the assigned stakeholders are utilized.

Step 3a: Consider Inputs and Outputs of Key Life Cycle Stages

Using the flow diagram template the LCT draft the life cycle path, indicating the main inputs and outputs at each stage. The template (Figure 6-2) includes the life cycle stages of manufacture, packaging/distribution, usage, service and EOL.

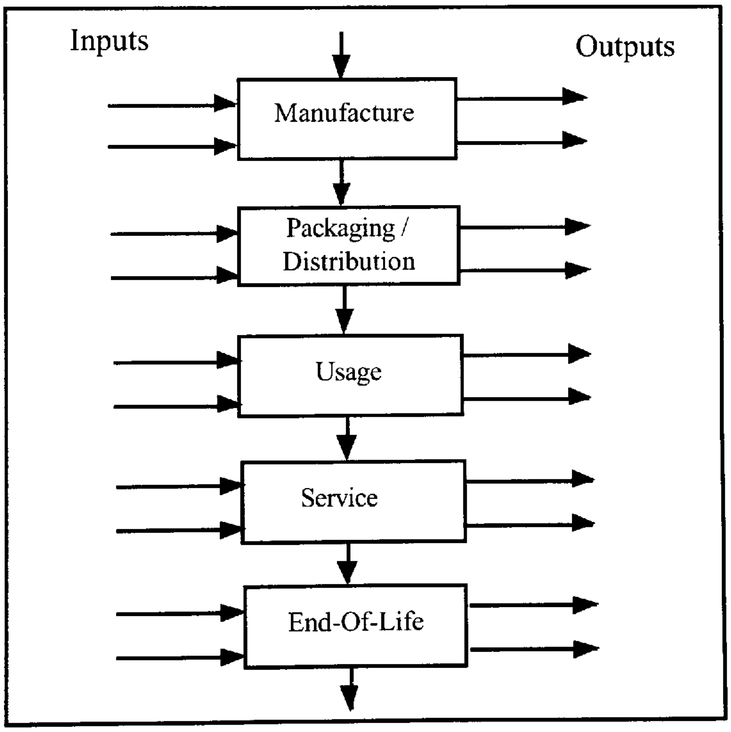

Figure 6-2 Life Cycle Flow Template

[58] When applicable, replace the word 'product' with 'component' or 'material' throughout the steps.

At least one stakeholder from each stage should be consulted to confirm the selections. If required, other similar templates can be used to examine the stages in further detail. These templates have a number of key functions including:

- To highlight the main resource flows for the product at various stages in its life cycle.
- To illustrate the typical daily usage transactions for each level of function.
- To illustrate the typical service and EOL asset management routes for the product.
- To ensure that all the key environmental considerations are determined.

Step 3b: Design 'Ideal' Concept

Based on the results from the life cycle strategy selection procedure, members of the LCT are assigned the task to develop 'Ideal' product concepts. These concepts can be radical in nature and are used to demonstrate a possible product of the future, taking advantage of the latest trends in ECD. The members should liaise with the coordinator who ensures that all the key stakeholders have input, and that the latest trends are considered. They are encouraged to use creativity techniques to develop a concept that best suits the selected life cycle strategy. For example, if the life cycle strategy is 'recycle (shred)' and 'dispose', the concept should be designed for ease of shredding, recycling and disposal at EOL. Here the stakeholders should include EOL asset managers. There are no set guidelines for designing these concepts although numerous techniques are available to facilitate idea generation, with the following creative thinking tools suitable for both incremental and radical improvement: 'Random Word', 'Empathy', 'Analogy' and 'PO'. Idea generation and unconstrained thinking can be supported through integrating environmental mind-sets into these traditional creative tools. Two additional approaches, which could be applied here, are the 'conceptual approach' identified by Van der Horst and Zweers (1994), and RLCA outlined in Graedel (1997).

Step 4: Confirm Matrix Categories

The matrix (Figure 6-6) which can incorporate both quantitative and qualitative data is used to assemble the environmental categories in a format suitable for evaluation. Using the provided list, and the completed flow diagram(s), the LCT confirms which of the matrix categories are applicable to the product. If deemed appropriate, additional categories can be added although research has established that the current list is sufficiently comprehensive for all electromechanical products and their packaging[59].

Step 5: Decide Category Weightings

Using the ECD category checklist (Appendix B) the LCT decides the respective weighting for the selected environmental categories. It is important to have a range of stakeholders involved in the weighting process to ensure there is no unfair bias towards certain categories. The weighting scale is used to semi-quantify the evaluation. This scale can be modified to suit the needs of the company, Table 6-3.

Table 6-3 Weighting Scale (0-10)

0	2	4	6	8	10
Not Important	Very Low Importance	Low Importance	Medium Importance	High Importance	Very High Importance

Step 6: Score Categories and Complete Matrix

Using the ECD category checklist (Appendix B) and through consulting the assigned stakeholders, the LCT score the product under each category using a scale of 0 to 10 (Table 6-4).

Table 6-4 Scoring Scale (0-10)

0	2	4	6	8	10
No Concern	Very Low Concern	Low Concern	Medium Concern	High Concern	Very High Concern

[59] If packaging is being assessed the category 'Product Cost' changes to 'Packaging Cost'.

This scale can be modified to suit the needs of the company. The score for each category can be determined through quantitative data where available and qualitative data using the 'body of knowledge'. The coordinator collects the scores from stakeholders unable to sit at the table. An example of the information available to assist in weighting and scoring the category 'product energy' is given in Table 6-5. Using the weighting and scoring system the worst scenario, i.e. maximum environmental concern or impact, is that a category would be rated 'very high importance' and would score 'very high concern' giving a 'Weight.Score' of 100. The best scenario, i.e., least environmental concern, is a 'Weight.Score' of 0. After scoring the categories the matrix should be completed and reviewed to ensure the LCT are happy with the outcomes.

Table 6-5 Category Scoring and Weighting

<table>
<tr><th>Category</th><th>Questions</th><th>Key Stakeholder(s)</th></tr>
<tr><td rowspan="3">Product Energy</td><td>Weighting - How important is this category in the context of the product being assessed and relative to the other categories?</td><td>Weighting this category requires the input of a range of stakeholders, who must include a product designer and user.

Weight: ______</td></tr>
<tr><td>Scoring - If the product is energy consuming, how well does it rate in terms of energy consumption during usage?

Generic Questions/Guidelines
Does the product consider the power source and power down modes?
Ensure product complies with any energy consumption standards, i.e. energy star.</td><td>Scoring this category requires the input of a range of stakeholders, who must include a product designer and user.

Score: ______</td></tr>
<tr><td colspan="2">Useful Additional Approach:
'Energy Indicators': Assumes that all environmental decisions can be brought back to one value - energy.</td></tr>
</table>

Based on the 8 approaches outlined by Van der Horst and Zweers (1994) there are a number of additional approaches suggested in the ECD category checklist. These include 'Usage Resource Indicator', and 'Service Indicator', where all environmental decisions can be brought back to one category, usage resource consumption and service respectively.

Step 7: Profile By Category and By Life Stage

The coordinator profiles the results by category and life cycle stage. These profiles or target plots help highlight the categories and stages of greatest concern, and provide a means of setting precise targets for improvement. The 'Weight.Score' numbers are used as performance indicators to measure improvements.

Step 8: Report and Prioritize

The coordinator prepares a report of the assessment results. The report is produced to communicate the results of the assessment and also to give advice about how to improve the product's environmental profile. The LCT reviews the report, setting priorities for re-design improvement. The prioritizing technique takes the list of 'weak' categories and stages and orders them in terms of environmental priority, customer priority, and company priority. Design improvements can also be ordered in a similar manner. The 'Ideal' product concept(s) are presented and reviewed to establish if any inherent features can be incorporated in the product.

Step 9: Improve

This step involves getting members of the LCT to generate new design options using creativity tools. Some of the features and characteristics of the 'Ideal' product concept(s) may be included in the new designs. The improvement stage involves three main stages, namely, preparation, idea generation and idea selection. The preparation involves clarifying the background and key requirements for the product. 'Mind Mapping' is especially useful in reducing the task down to its basic elements. After idea generation the concepts are clustered together. The LCT then undertakes some initial decision making and idea filtering. Where necessary, key external stakeholders such as sub-contractors, suppliers and EOL asset managers, who may not be present at the table, are consulted. For idea or concept selection, 'Comparison Matrices' have been found to be very effective.

Step 10: Repeat Procedure

Return to 'Step 6' to weight and score the environmental categories for the new improved concept(s). The LCT then undertakes a final concept evaluation and selection. Where necessary key external stakeholders, who may not be present at the table, are consulted.

6.3.1 Life Cycle Strategy

The life cycle strategy step-by-step procedure is given in Figure 6-1. This procedure and accompanying guidelines (Appendix B) enables the LCT to select a suitable strategy for the product under assessment. It involves completing a tailor–made worksheet that is outlined in Figure 6-3 and Figure 6-5 respectively. The key stakeholders identified through the research are as follows: marketing, materials expert, product designer, manufacturing personnel, management, user, service, EOL asset manager and ECD experts. Key external stakeholders such as users and EOL asset managers, who may not be present at the table, should be consulted.

Step 1: General Guidelines

Using the guidelines (Appendix B), the LCT comes to an initial decision on the product life span, and whether it should have a SLC or MLC. The 'ideal' scenario can be devised through consulting a group of ECD experts, while the 'actual' scenario can be established through surveys of existing products. The LCT may have to use their 'gut feeling' to make the initial recommendations on the life cycle strategy and life span. The allotted spaces on the life cycle strategy worksheet need to be completed, Figure 6-3.

Step 2: MLC Factors

The LCT considers the product in terms of the 6 key MLC factors (Appendix B), and decides whether a SLC or a MLC would be more favorable. Detailed information is available on 'product issues' and 'infrastructure' collection options to assist in the decision making. If a SLC is the more favorable option for the product, it is designated a qualitative score of '1'. If it is unclear whether a SLC or a MLC would be more favorable, it is designated a qualitative score of '2'. Finally, if a MLC is the more favorable option, it is designated a qualitative score of '3'. The scores are added to the worksheet, Figure 6-3. A low score (6-10) indicates suitability to a SLC while a high score (14-18) indicates suitability to a MLC.

<table>
<tr><td colspan="4" rowspan="2">Item:</td><td colspan="3" rowspan="2">Level:</td><td colspan="4">Date:</td></tr>
<tr><td colspan="4">Rev:</td></tr>
<tr><td rowspan="3">Step 1
General Guidelines</td><td colspan="3">Ideal</td><td colspan="4">Actual</td><td colspan="3">Recommended</td></tr>
<tr><td colspan="3">SLC MLC</td><td colspan="4">SLC MLC</td><td colspan="3">SLC MLC</td></tr>
<tr><td colspan="3">Life Span:</td><td colspan="4">Life Span:</td><td colspan="3">Life Span:</td></tr>
<tr><td rowspan="8">Step 2
MLC Factors</td><td colspan="5">Factors</td><td colspan="5">SLC ◄─► MLC
1 - 2 - 3</td></tr>
<tr><td colspan="5">Cost</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Awareness</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Product Issues</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Legislation</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Infrastructure</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Stakeholder Co-operation</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Total</td><td colspan="5"></td></tr>
<tr><td rowspan="2">Step 3
EOL Reasons</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 6-3 Life Cycle Strategy Worksheet (Steps 1 to 3)

Step 3: EOL Reasons

The LCT reviews the product in terms of the common reasons as to why products reach EOL or obsolescence, where it is no longer able to perform its intended function (Appendix B). The reasons that are most likely to apply to the product are circled on the allotted space on the worksheet, Figure 6-3. If applicable, additional reasons can added to the list. Generally, if a large number of reasons apply to the product this indicates that a SLC may be the more appropriate strategy.

Step 4: Level of Function

The LCT considers the product in terms of the three levels of function: primary, secondary and tertiary. A functional tree will assist in developing the levels of function, Figure 6-4.

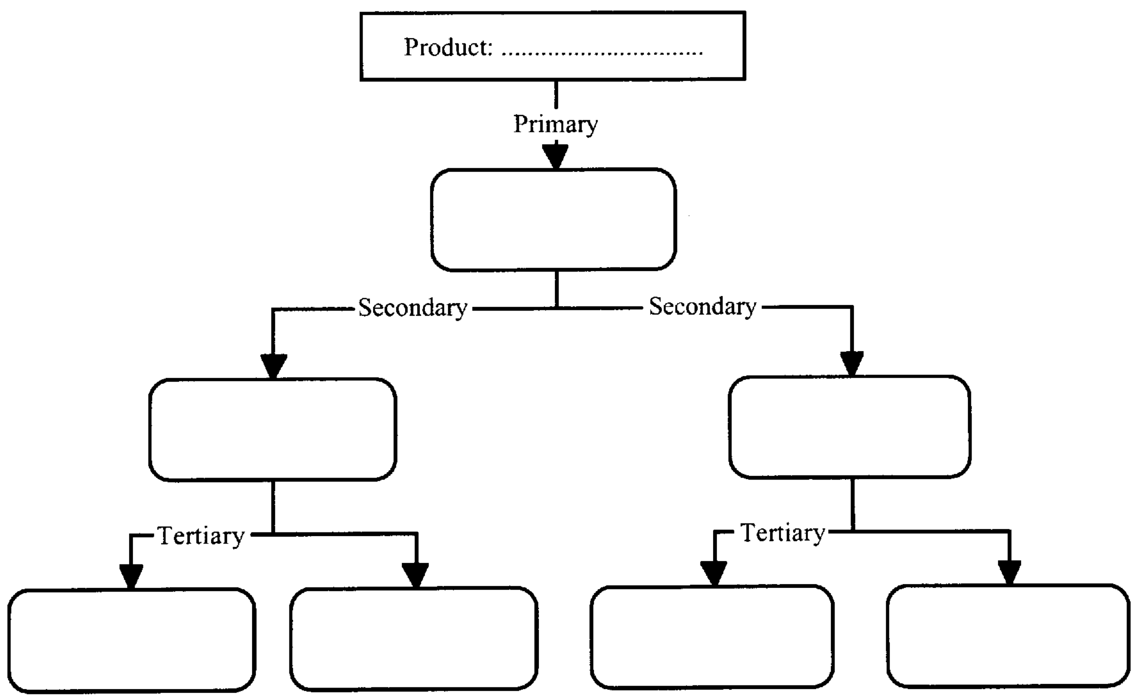

Figure 6-4 Functional Tree Template

Decisions are made on the number of lives and product life span for each level of function. The allotted spaces on the worksheet must be completed, Figure 6-5. Products with different levels of function are termed 'multi-level products'.

Step 5: Routes

The LCT considers the possible routes available to the product, with decisions made on the most appropriate ones. These routes are then circled on the worksheet, Figure 6-5. If service, reuse, remanufacture and recycle (disassemble) are selected, the LCT must carry out a disassembly analysis, and EOL valorization using templates similar to Table 6-6 and Table 6-7 respectively.

Table 6-6 Disassembly Analysis Template

Item	Item(s) Attached To	Mechanical Connection	Electrical Connection	Tools Required

Table 6-7 EOL Valorization Template

No.	Item	Route	Potential Value

Step 6: Life Cycle Strategy Selection

The LCT reaches a final decision on the appropriate life cycle strategy based on the previous 5 steps. The product is scored using Table 6-4 in terms of suitability for a MLC. Key external stakeholders such as users and EOL asset managers, who may not be present at the table, should be consulted in the scoring process. A low score (<5) indicates a MLC may be the best strategy, whereas a high score (>5) indicates a SLC may be more appropriate. If the product is to have an MLC, the LCT decides how important the category is in the context of the product being assessed, and relative to the other categories using the weighting scale (Table 6-3). Finally the allotted spaces on the worksheet are completed, Figure 6-5.

<table>
<tr><td rowspan="7">Step 4
Levels of Function</td><td>Level</td><td>Function</td><td colspan="2">Number of Lives</td><td colspan="2">Life Span</td></tr>
<tr><td rowspan="2">Primary (P)</td><td rowspan="2"></td><td>1</td><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Secondary (S)</td><td rowspan="2"></td><td>1</td><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Tertiary (T)</td><td rowspan="2"></td><td>1</td><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="3">Step 5
Routes</td><td>Service</td><td>Reuse</td><td colspan="4">Remanufacture</td></tr>
<tr><td colspan="2">Recycle (Disassemble)</td><td colspan="4">Recycle (Shred)</td></tr>
<tr><td colspan="2">Heat Recovery</td><td colspan="4">Disposal</td></tr>
<tr><td rowspan="5">Step 6
Life Cycle
Strategy
Selection</td><td colspan="2" rowspan="2">MLC Score = / 10</td><td colspan="2">SLC</td><td colspan="2">MLC</td></tr>
<tr><td colspan="4">Number of Lives</td></tr>
<tr><td colspan="2" rowspan="2">Number of Lives per Level</td><td>P</td><td>S</td><td>T</td><td>Total</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Life Span</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Approved By:</td></tr>
</table>

Figure 6-5 Life Cycle Strategy Worksheet (Steps 4 to 6)

6.3.2 Novel Stakeholder ECD Matrix

The environmental categories are linked to the stage of application in the ECD matrix template, Figure 6-6.

Stage	No	Environmental Category	Weight	Score	Weight.Score
Manufacturing	1	Material Issues			
	2	Environmental Manufacturing			
	3	Manufacturing Issues			
Distribution	4	Shipping & Storage			
	5	Packaging Recycling			
Usage	6	Sustainable			
	7	Energy Consumption			
	8	Resource Consumption			
	9	Physical Properties			
	10	Quality/Reliability			
	11	Health & Safety			
	12	Human Factors			
	13	Features/Functionality			
	14	Product Cost			
	15	Aesthetics			
Service	16	Service Issues			
End-of-Life	17	Product Recycling			
	18	Disposal			
ECD Measure$_{SLC}$ or Total Weight.Score (Single Life Cycle) or TWS$_{SLC}$					
Multiple Life	19	Multiple Life Cycle Issues			
ECD Measure$_{MLC}$ or Total Weight.Score (Multiple Life Cycle) or TWS$_{MLC}$					

Figure 6-6 Novel Stakeholder ECD Matrix

6.4 Testing and Validation of New ECD Approach

Draft versions of the approach had been previously tested in three industrial case studies and a series of modules for trainee product designers at the UOG. The main findings from testing through the industrial case studies are outlined in Section 5.1.10 and Section 5.3.2.5 respectively. 30 trainee product designers tested the developing methodology through undertaking a 12-week ECD study of a range of electromechanical products. The results and feedback were extremely positive, while the participants felt the approach greatly encouraged 'life cycle thinking'. The approach was refined as a result of the testing. Details of the testing undertaken by the two independent assessors on a mobile phone, and photocopier, respectively are provided in the next sections.

6.4.1 Product Study 1: Mobile Phone

Using the ECD analysis and improvement framework (Figures 5-15 and 5-55 respectively), Mr. P. Youlden, Product Designer, designed a new computer keyboard for Alps (Figure 5-29), which had a number of environmental benefits (Ademe, 1999). Mr. Youlden undertook an analysis of a mobile phone using the 'Multi-Stakeholder Abridged ECD Approach'. The product level was selected for the mobile phone, Figure 6-7.

Item: MOBILE PHONE				Level: PRODUCT				Date: 22/05/00		Rev: 1
Step 1 General Guidelines	Ideal			Actual				Recommended		
	SLC	MLC		SLC	MLC			SLC	MLC	
	Life Span: 5			Life Span: 1				Life Span: 1		
Step 2 MLC Factors	Factors				SLC ↔ MLC 1 - 2 - 3					
	Cost				1					
	Awareness				1					
	Product Issues						2			
	Legislation						2			
	Infrastructure						2			
	Stakeholder Co-operation				1					
	Total				9					
Step 3 EOL Reasons	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15					

Figure 6-7 Mobile Phone Life Cycle Strategy Worksheet (Steps 1 to 3)

Using the views of the ECD experts (Section 5.2.5.3) the ideal life cycle strategy was a SLC of 5 years. Through discussions with key stakeholders the actual life cycle strategy was a SLC of 1 year. When the other steps were considered, it was decided to give the product a SLC, it scored '8' for the category of 'multiple life cycle', with multi-levels, Figure 6-8. The routes selected were recycle (shred) and disposal. The product life span at the primary level was 1 year, while the life span at the secondary and tertiary levels was set at 2 and 5 years respectively. These levels may not be implemented as they predominantly depend on the discretion of the primary user.

<table>
<tr><td rowspan="7">Step 4
Levels of Function</td><td>Level</td><td>Function</td><td colspan="2">Number of Lives</td><td colspan="2">Life Span</td></tr>
<tr><td rowspan="2">Primary (P)</td><td rowspan="2">MOBILE COMM.</td><td>1</td><td>2</td><td>1</td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Secondary (S)</td><td rowspan="2">ORGANISER</td><td>1</td><td>2</td><td>2</td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Tertiary (T)</td><td rowspan="2">DOOR STOP</td><td>1</td><td>2</td><td>5</td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="3">Step 5
Routes</td><td>Service</td><td>Reuse</td><td colspan="4">Remanufacture</td></tr>
<tr><td colspan="2">Recycle (Disassemble)</td><td colspan="4">Recycle (Shred)</td></tr>
<tr><td colspan="2">Heat Recovery</td><td colspan="4">Disposal</td></tr>
<tr><td rowspan="4">Step 6
Life Cycle Strategy Selection</td><td colspan="2">MLC Score = 8 / 10</td><td colspan="2">SLC</td><td colspan="2">MLC</td></tr>
<tr><td colspan="2"></td><td colspan="4">Number of Lives</td></tr>
<tr><td colspan="2" rowspan="2">Number of Lives per Level</td><td>P</td><td>S</td><td>T</td><td>Total</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>1 (+2)</td></tr>
<tr><td></td><td colspan="2">Life Span</td><td>1</td><td>2</td><td>5</td><td>1 (+7)</td></tr>
<tr><td>Approved By:</td><td colspan="6">P. YOULDEN</td></tr>
</table>

Figure 6-8 Mobile Phone Life Cycle Strategy Worksheet (Steps 4 to 6)

Completing the matrix resulted in the following profiles, Figure 6-9 and Figure 6-10. The average weightings from the study of PCs were used in the assessment.

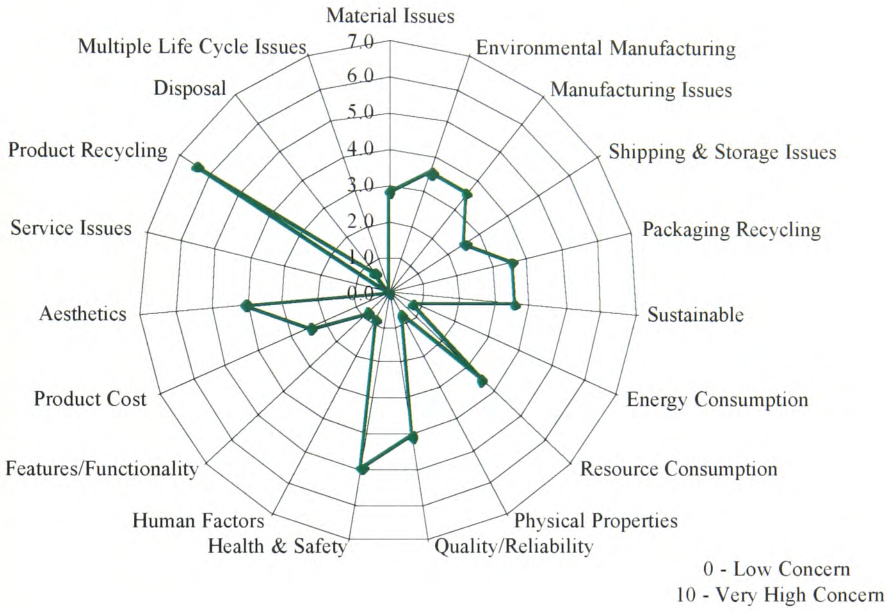

Figure 6-9 A Profile of Environmental Categories (Mobile Phone)

The profiles do not include a 'Weight.Score' for the 'service' and 'multiple life cycle' categories and stages, as these were not selected as part of the life cycle strategy. The categories of highest concern were found to be 'product recycling' and 'health and safety'. The stages of most concern were 'EOL' and 'manufacturing'. These will be considered in the re-design. The 'TWS_{SLC}' or 'ECD $measure_{SLC}$' for the product was '2.8'. This measure can be used when comparing the product to other design versions. The study verified that the approach is effective, although it had a number of restrictions, most notably that it was carried out by only one person, who applied weightings for PCs[60]. In industrial practice the LCT should be involved, using scores and weightings devised by a range of stakeholders for the product group. Mr. Youlden was very positive about the approach[61]. It forced him to

[60] 'Step 1' of the 'Life Cycle Strategy' procedure was an exception.

[61] Contact details for Mr. Youlden are given in Appendix A.

consider criteria and issues that he would not have previously accounted for. He found the approach practical, user-friendly and quick to use, and felt that it would be extremely cost-effective.

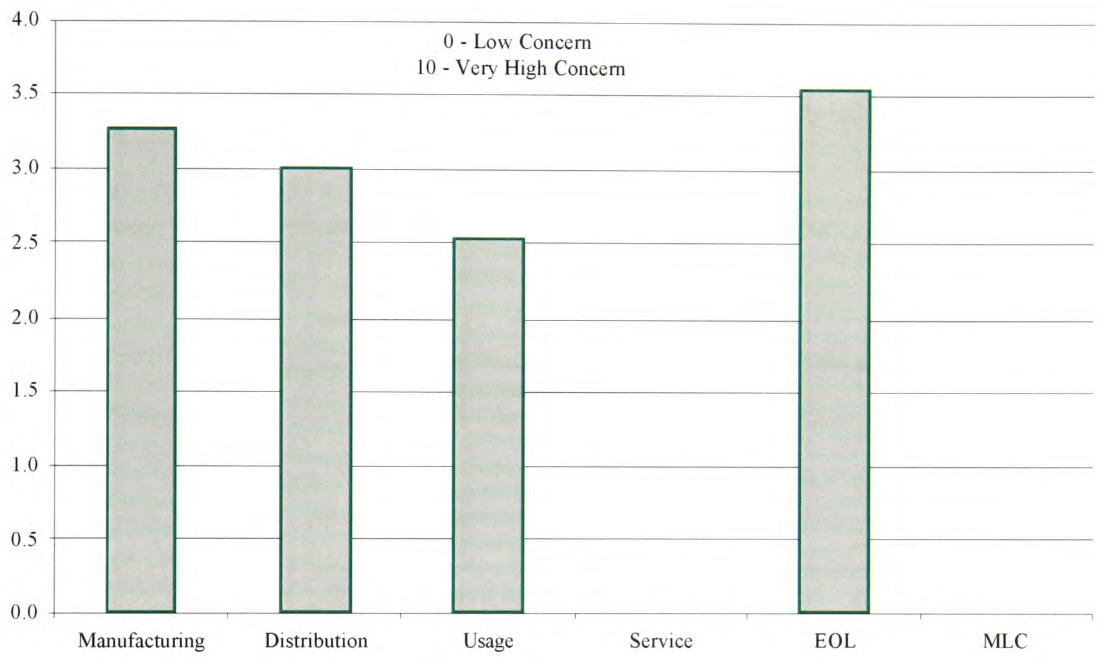

Figure 6-10 A Profile of Environmental Life Cycle Stages (Mobile Phone)

6.4.2 Product Study 2: Photocopier

Using the ECD analysis and improvement framework (Figures 5-15 and 5-55 respectively), Mr. S. Lee, Environmental Product Design Advisor, designed a new hazard lamp for Transco, which included a number of environmental benefits[62]. Mr. Lee successfully carried out an

[62] The design was awarded the Welsh Development Agency Technology Prize for Energy, along with an Institute of Engineering Design Award.

assessment of a photocopier, using the 'Multi-Stakeholder Abridged ECD Approach'. The product level was selected for the photocopier, Figure 6-11.

<table>
<tr><td colspan="4">Item:
PHOTOCOPIER</td><td colspan="4">Level:
PRODUCT</td><td colspan="3">Date: 09/06/00
Rev: 1</td></tr>
<tr><td rowspan="3">Step 1
General Guidelines</td><td colspan="3">Ideal</td><td colspan="3">Actual</td><td colspan="4">Recommended</td></tr>
<tr><td colspan="3">SLC MLC</td><td colspan="3">SLC MLC</td><td colspan="4">SLC MLC</td></tr>
<tr><td colspan="3">Life Span: 8</td><td colspan="3">Life Span: 8</td><td colspan="4">Life Span: 10</td></tr>
<tr><td rowspan="8">Step 2
MLC Factors</td><td colspan="5">Factors</td><td colspan="5">SLC ◄► MLC
1 - 2 - 3</td></tr>
<tr><td colspan="5">Cost</td><td colspan="2"></td><td colspan="2"></td><td>3</td></tr>
<tr><td colspan="5">Awareness</td><td colspan="2">1</td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Product Issues</td><td colspan="2"></td><td colspan="2">2</td><td></td></tr>
<tr><td colspan="5">Legislation</td><td colspan="2"></td><td colspan="2">2</td><td></td></tr>
<tr><td colspan="5">Infrastructure</td><td colspan="2"></td><td colspan="2">2</td><td></td></tr>
<tr><td colspan="5">Stakeholder Co-operation</td><td colspan="2"></td><td colspan="2">2 ◄</td><td>► 3</td></tr>
<tr><td colspan="5">Total</td><td colspan="5">12.5</td></tr>
<tr><td rowspan="2">Step 3
EOL Reasons</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 6-11 Photocopier Life Cycle Strategy Worksheet (Steps 1 to 3)

Using the views of the ECD experts (Section 5.2.5.3) the ideal life cycle strategy was a MLC of 8 years. Through discussions with key stakeholders the actual life cycle strategy was also a MLC of 8 years. When the other steps were considered it was decided to give the product a MLC, it scored '3' for the category of 'multiple life cycle', with multi-levels, Figure 6-12. The routes selected were service, reuse, remanufacture, recycle (disassemble) and disposal, with priority assigned to the first three routes respectively. The product life span at the primary level was 10 years, while the life span at the secondary and tertiary levels was set at 2 and 5 years respectively. The tertiary level may not be implemented as it predominantly depends on the discretion of the secondary user.

<table>
<tr><td rowspan="7">Step 4
Levels of Function</td><td>Level</td><td>Function</td><td colspan="2">Number of Lives</td><td colspan="2">Life Span</td></tr>
<tr><td rowspan="2">Primary (P)</td><td rowspan="2">COPIER</td><td>1</td><td>2</td><td>7</td><td>3</td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Secondary (S)</td><td rowspan="2">LIGHT BOX</td><td>1</td><td>2</td><td>2</td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">Tertiary (T)</td><td rowspan="2">STORAGE UNIT</td><td>1</td><td>2</td><td>5</td><td></td></tr>
<tr><td>3</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="3">Step 5
Routes</td><td>Service</td><td>Reuse</td><td colspan="4">Remanufacture</td></tr>
<tr><td colspan="2">Recycle (Disassemble)</td><td colspan="4">Recycle (Shred)</td></tr>
<tr><td colspan="2">Heat Recovery</td><td colspan="4">Disposal</td></tr>
<tr><td rowspan="5">Step 6
Life Cycle
Strategy
Selection</td><td colspan="2" rowspan="2">MLC Score = 3 / 10</td><td colspan="2">SLC</td><td colspan="2">MLC</td></tr>
<tr><td colspan="4">Number of Lives 2</td></tr>
<tr><td colspan="2" rowspan="2">Number of Lives per Level</td><td>P</td><td>S</td><td>T</td><td>Total</td></tr>
<tr><td>2</td><td>1</td><td>1</td><td>2 (+2)</td></tr>
<tr><td colspan="2">Life Span</td><td>10</td><td>2</td><td>5</td><td>10 (+7)</td></tr>
<tr><td>Approved By:</td><td colspan="6">S. LEE</td></tr>
</table>

Figure 6-12 Photocopier Life Cycle Strategy Worksheet (Steps 4 to 6)

Completing the matrix resulted in the profiles given in Figure 6-13 and Figure 6-14. The categories of highest concern were found to be 'quality and reliability', 'physical properties', 'service issues' and 'resource consumption'. The stages of most concern were 'service' and 'usage'. These will be considered in the re-design. The 'TWS_{MLC}' or '$ECD\ measure_{MLC}$' for the product was '4.8'. This measure can be used when comparing the product to other design versions.

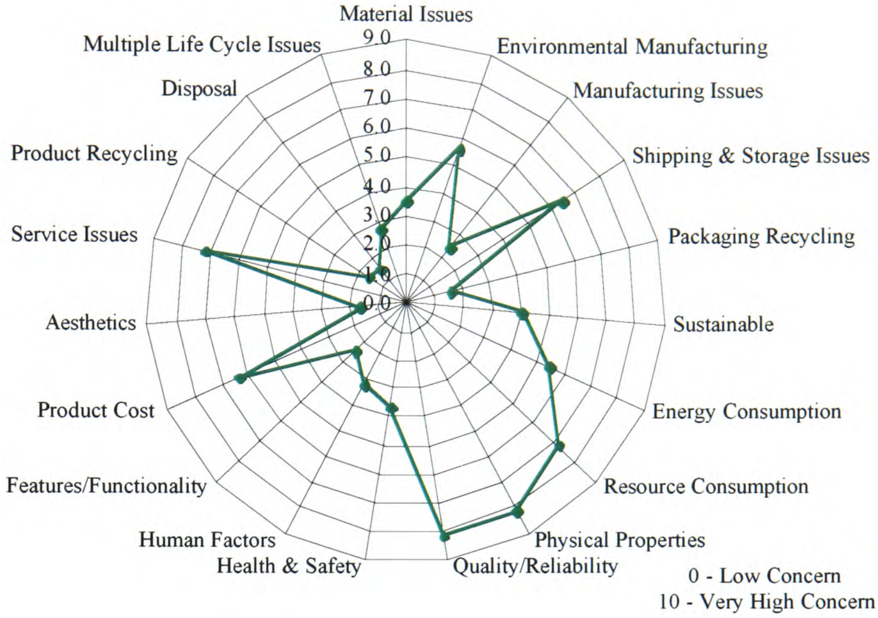

Figure 6-13 A Profile of Environmental Categories (Photocopier)

Using the information from the life cycle strategy worksheet and matrix analysis, an 'ideal' concept photocopier was designed to compare with the original design, Figure 6-15. In its secondary level the photocopier functions as a light box, while at the tertiary level it can be used as a storage unit.

The study verified that the approach is effective, although it had a number of restrictions most notably it was carried out by one-person only. In industrial practice the LCT should be involved, while a range of stakeholders for the product group should devise the scores and weightings. Mr. Lee was very positive about the approach, finding it extremely beneficial and efficient[63]. The life cycle strategy selection process enabled him to investigate SLC and MLC routes that he had not previously considered, and assisted him in identifying new levels of function for the product. This resulted in the development of a novel concept.

[63] Contact details for Mr. Lee are given in Appendix A.

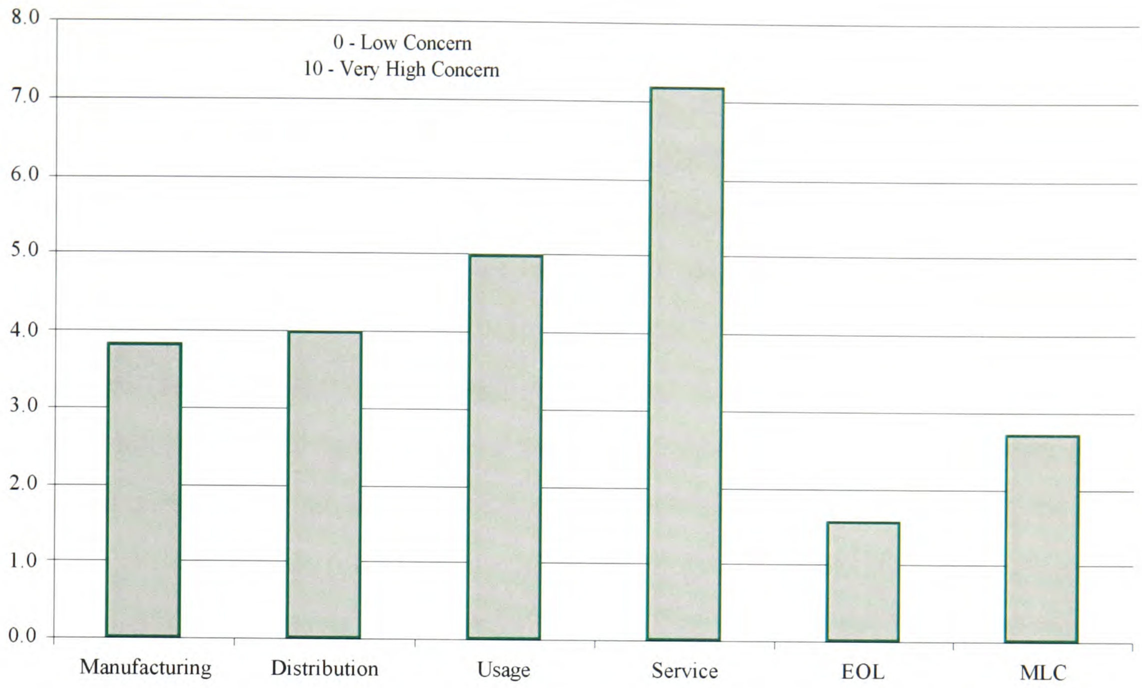

Figure 6-14 A Profile of Environmental Life Cycle Stages (Photocopier)

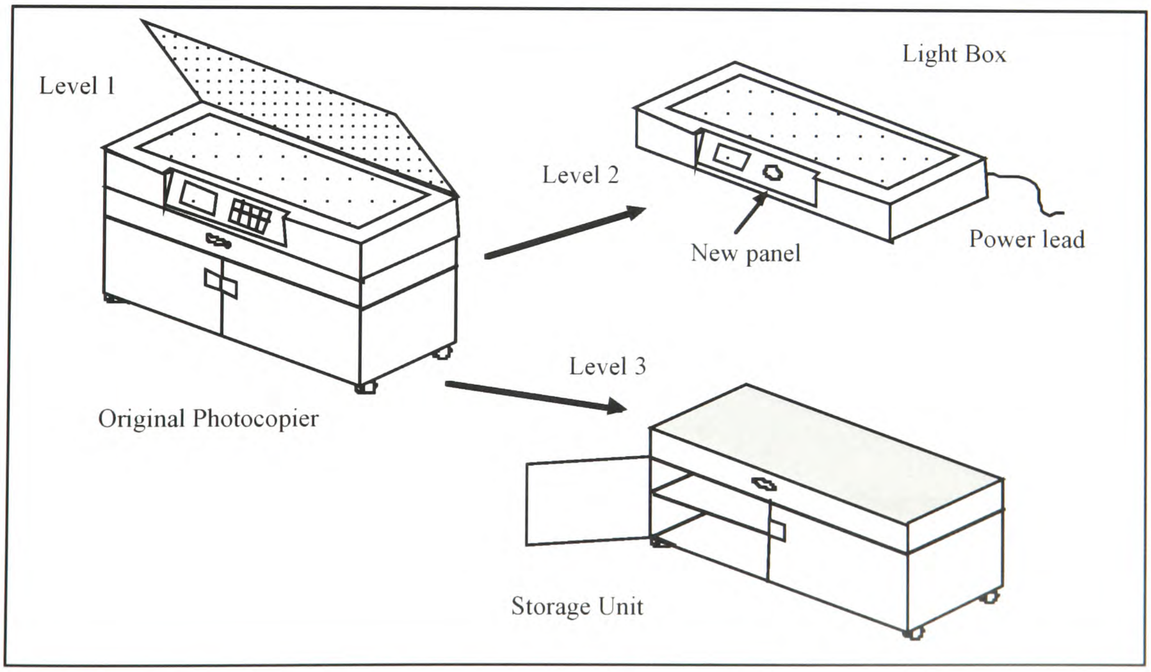

Figure 6-15 'Ideal' Photocopier Concept

6.5 Advantages and Implications of using the Approach

The paper-based qualitative approach is user-friendly, quick to use and cost-effective, and provides an effective way of assessing a product, component or material. It has all the advantages of the common abridged approaches but is more comprehensive, considering both the role of stakeholders and multiple life cycles. The approach can be continually updated through further surveys and case studies. Any electromechanical product and its packaging can be assessed using the approach, although a degree of interpretation may be required. The approach allows the efficient extraction of relevant data and information relating to the product in question. All the key environmental considerations can be analyzed at the design stage. The qualitative scale provides a means of setting priorities, and monitoring progression and continuous improvement. The approach ensures that multi-criteria value judgements are not based on an individual assessor, but a group of stakeholders who participate in deciding the life cycle strategy, and weighting and scoring the categories. While completing the assessment it becomes clear how the environmental impact of the product in question may be reduced. The life cycle strategy worksheet and procedure allows key decisions such as the life span, and number of life cycles to be made as early as possible in the design process. The ECD matrix and profiling provides a simple and clear picture of the environmental categories that need to be considered in the design of the product in question. Through its generic nature and inherent guidance, the approach is particularly useful for a LCT with a minimum knowledge of environmental concerns. Although the approach may be used at different stages in the design process, it will be more effective and beneficial if it is used as early as possible, and as part of a GCE process.

If you leave out any of the part of the approach, for example, consulting key stakeholders or weighting of the categories, you can still complete the assessment but the accuracy of the result will be reduced. Although the approach is based on electromechanical products and their packaging, its qualitative nature should allow many of the principles to be transferable to other product industries[64]. This advantage of being qualitative in nature can also be viewed as an inherent weakness. Taken literally the scoring and weighting scales could give the impression that the answer to perfect ECD is through scoring a '0'. It must be remembered that these scales are relative. Completing all steps of the approach does not guarantee an ideal product. Compromises with traditional requirements will always have to be made. Abridged approaches have in-built limitations, but as the new methodology considers the full life cycle, it should typically identify 80% of the useful ECD actions that could be taken. Although, the approach does consider sustainability, through including a 'sustainable' category in the usage stage, it is largely an ECD approach and not a sustainable design tool. If a company finds that their product is at the top of the ECD scale, they should implement sustainable tools and techniques. As an aid to academia, the approach serves as a starting point to discover more about the life cycle of products, and how to implement ECD. It uncovers some important areas that trainee product designers need to consider when designing environmentally conscious products. As an aid to industry, the approach provides a quick and efficient way of analyzing and improving their family of products while developing close links with their key external stakeholders. It should be of special benefit to SMEs. The industrial case studies showed how such a cost-effective approach even if completed on a small scale, can provide useful and practical results. To be successful the approach will require the full backing of all levels of management. It is recommended that each ECD step is signed off and approved before progression.

[64] The trainee product designers successfully tested the developing approach on other product groups such as a disposable razor and biro.

6.6 Summary of New ECD Approach

This chapter outlined the new ECD approach along with testing it on two product studies using independent assessors. The next section presents the final conclusions for the thesis in terms of the original objectives, and the novel contribution to knowledge.

7 Conclusions

The following conclusions can be drawn from the work carried out to develop and validate the new 'Multi-Stakeholder Abridged ECD Approach':

ECD relies on the close co-operation and input of many different stakeholders, both within and external to a company, the tasks and responsibilities of which all have an impact on different stages of the design process. These stakeholders can influence the products environmental impact and have a key role to play in the life of the product, from design through to EOL. They should therefore be involved in the product development process.

By conducting an in-depth literature review, and through a novel approach of surveys (questionnaires and interviews), case studies, and a focus group, a stakeholder 'body of knowledge' was gathered for electromechanical products and their packaging. The 'body of knowledge' was collected from a range of stakeholders, namely the LCT, not just internal CFT members.

Stakeholders, claim to be willing to pay extra for PCs with environmental benefits and to participate in product return schemes. This is consistent with previous findings. 'Product recycling', 'material issues', 'health and safety' and 'environmental manufacturing issues' feature prominently as key environmental criteria for PCs. Stakeholders require more information on these criteria, and want ECD legislation to focus on them. Stakeholders expressed the view that the government should have the main role in pushing environmental criteria. In deciding their importance the government and users should have the main roles.

This 'body of knowledge' consists of the environmental criteria, a list of 19 environmental categories, that stakeholders consider important in evaluating alternative designs. These categories are linked to the key life cycle stages of a product: manufacture, packaging/distribution, use, service and EOL asset management. These categories can be applied to a range of electromechanical products and their packaging.

In terms of weighting the 'top 5' environmental criteria, the views and opinions of similar stakeholders were found to be different. It was possible to develop generic category weightings for PCs, but not for all electromechanical products. There are numerous other influences that can affect the weighting process. The chosen approach for devising the environmental category weightings recommends consulting assigned key stakeholders to decide on the weightings. An ECD category checklist was developed to assist in weighting and scoring these categories when evaluating electromechanical products and their packaging. It is recommended that the key influencing and varying factors identified in the research be reviewed as part of the ECD approach to ensure they do not adversely affect the outcomes of the assessment.

As the participants expressed difficulty with the task of weighting stakeholders, and life cycle stages, and there was some inconsistency in their selections, it was decided not to apply these weightings. However, the LCT may decide to prioritize certain stages, or the views of certain stakeholders during the assessment.

The 'body of knowledge' also includes other factors and principles that stakeholders consider important in evaluating alternative designs, and selecting a suitable life cycle strategy. These include generic guidelines, MLC factors, EOL routes, levels of function, and reasons why products reach obsolescence. These are reviewed as part of the life cycle strategy selection procedure. The EOL routes, and some of the generic guidelines and reasons why products reach obsolescence, confirm previous findings.

The 'body of knowledge' is of global benefit, as the categories and MLC factors were found to be applicable to a range of products. This body of knowledge' has the potential to be continually updated through consultation with other stakeholders and further case studies, while the relative weightings have the potential to be modified for different electromechanical products.

A methodology, incorporating this 'body of knowledge' was developed into a 'Multi-Stakeholder Abridged ECD Approach'. Due to the diversity of skills required, and the time constraints placed upon a design team, qualitative tools that were quick and simple to use, and did not require the collection of vast quantities of data were found to be appropriate for the methodology. This is consistent with previous research. The matrix-based approach consists primarily of a life cycle strategy worksheet, input-output flow diagrams, matrix, profiles, checklists, and improvement tools. The matrix-based approach was found to be particularly effective and advantageous. Matrices allow the complex interrelation of the different life cycle stages to be represented in a clear and simple manner. Also, the designers currently use matrix-based techniques in other aspects of design.

Completion of the life cycle strategy worksheet, using the information and data available, develops a clear picture of the strategy that should be selected when designing the product in question. At the design stage, the LCT follows six clearly defined stages before coming to a final decision on the most suitable life cycle strategy. The worksheet assists in defining environmental priorities and devising design rules, thereby supporting other decision-making actions at various stages of the product's life cycle. It facilitates the LCT in making decisions on the product life span, whether it should have a SLC or MLC, and what to do with it when it becomes finally obsolete through offering effective guidance. This life cycle strategy selection process is ideal for use and application by SMEs with limited resources and time. This information and knowledge was not previously available in an abridged cost-efficient, quick and user-friendly format.

This 'Multi-Stakeholder Abridged ECD Approach' takes account of the role of stakeholders in ECD, their opinions and views. It offers design advice relating to each stage of a SLC or MLC product, and can be applied to a generic family of electromechanical products and their packaging. Stakeholder information is presented in a format that can be applied, in order that all the key environmental considerations are identified, and analyzed, at the design stage. The approach is based on the 'analyze-report-prioritize-improve' framework, outlined in previous research findings, and is seen as a perfect mechanism for incorporating stakeholder requirements and strategies in the ECD process, with key LCT members, participating at predetermined stages. The approach ensures that multi-category value judgements are not based on an individual assessor, but on a group of stakeholders who participate in deciding the life cycle strategy, and weighting and scoring the categories. Through consulting these key stakeholders dissimilar environmental effects, such as recycling and disposal considerations, can be weighted against each other to clarify which design is less harmful. The surveys and case studies were used to determine the assignment of stakeholders to certain stages of the approach. This approach has the added advantage of being able to analyze traditional design requirements, such as reliability, alongside environmental considerations, such as suitability for recycling.

Stakeholder participation and co-operation is key to the successful implementation of the abridged approach. One person is assigned to co-ordinate the approach. Although this coordinator can individually make the required decisions, he or she is encouraged to work as part of an assessment team, the LCT. If stakeholders cannot take their place at the table, the coordinator should consult at least one stakeholder from each stakeholder grouping assigned.

The new approach can be implemented as part of a GCE process, and it looks further than the short-term goal of profit orientation to force designers to take into account a wider range of stakeholder considerations.

A draft version of the approach was used to analyze, score and improve designs in three industrial case studies. It was also tested and refined in a series of modules for trainee product designers. The approach was found to be very effective in the pursuit of environmental analysis and improvement. The industrial case studies demonstrated how such an abridged approach, even if completed on a small scale, can provide useful and practical results. They also established that there is a way forward in ECD for SMEs without having to commit too many resources.

Two independent assessors successfully tested the approach on a mobile phone and a photocopier.

The approach should be used for re-designing an existing electromechanical product and its packaging or comparing alternative designs. It can also be used for designing novel versions, although it is tailored towards the former applications. Due to its generic nature the approach may be used at any stage of the design process. As found in previous research, it is preferable to use the ECD tool as early as possible, so as to expedite the most-wide ranging changes to the design.

8 Recommendations for Further Research

The essence of this research has been to understand, and present, a novel abridged ECD approach, that considers the role of stakeholders for SLC and MLC electromechanical products and their packaging. This 'Multi-Stakeholder Abridged ECD Approach' has been tested and validated. This section includes recommendations for work that would further the scope and extend the knowledge base of the research presented in this thesis. There are a number of possibilities for further research that would be beneficial. The following areas were identified as offering the best opportunities:

Two independent assessors successfully tested the new approach. It should now be tested and refined in industry on a wider scale, on both SMEs and larger companies, using the LCT, and a range of electromechanical products, components, and materials.

It is believed that the new approach could be successfully tested on other product groups. Any similarities across product groups could be incorporated into the approach, and differences kept as a database specific to each. Some initial trials on non-energy consuming products were found to be successful.

Computerization of the method may eliminate much of the repetitive work required in the approach, such as inserting data in the strategy worksheet, matrix and flow diagrams. A computerized version would have to be compatible with the range of current systems used in industry.

A database of the life cycle strategy worksheets needs to be developed and maintained. This would facilitate the transfer of information, and linking between products. It should also increase the efficiency of the exercise while enabling enable companies who are new to the ECD process to gain vital information.

'Product classifiers' such as life cycle length, product price, service frequency, etc., should be investigated further, to see if useful links could be established between product groups. Development of a database of product classifiers could facilitate the ECD process.

The stakeholder 'body of knowledge' could be further developed through additional surveys and case studies, while the stakeholders could be further categorized under the varying factors, in areas such as product, profession, and level of environmental expertise. They could also be categorized by country of residence; to build a picture of the differences in stakeholder opinions between the countries analyzed.

It would be useful to compare the results from using this approach with a range of products to other quantitative and qualitative tools, such as the ERP matrices.

The current improvement tools are useful but more research is required on the effectiveness of established creativity tools in the pursuit of environmental improvement. Techniques that have been successfully applied in management and quality situations may be able to assist the designer in significantly improving the environmental performance of a product. This thesis began to briefly examine the effectiveness of some creativity tools. Further detailed research work is required.

Research is required into what characterizes 'ideal concepts' and the best methods and techniques to develop them. This should include further research into multi-level products.

As highlighted in the keyboard case study, there is a real need to investigate the effectiveness of alternative natural biodegradable materials, such as hemp, as a replacement for plastic and other constituents in electromechanical products.

An investigation is required into how the approach interfaces with the new and evolving topic of 'knowledge management'. Stakeholders are the integral part of a successful knowledge management system. Therefore, the link between ECD, this multi-stakeholder approach, and knowledge management should be explored.

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APPENDICES

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

Type No. 1: Used in 'SURVEY A'

A Background Details

1 - Title: Mr. Mrs Ms. Dr. Other....

2 - Age Group: 0-20 21-35 36-50 51-64 65+

3 - Gender: Male Female

4 - Nationality: ....

5 - Country of Residence: ....

6 - Occupation: ....

7 - Are you currently a user of these products? Yes/No
If yes, specify which ones..

8 - Name of organization you are employed by: ....

9 - Job Title: ....

B Environmental Issues

10 - Are you a subscribing member of any environmental groups? Yes/No
If yes, please specify which ones ....

11 - Do you take an active role in any environmental groups through participation in meetings, demonstrations etc? Yes/No
If yes, please specify which ones ....

12 - Using Scale A indicate your degree of concern with environmental issues at each level.

Scale A

1	2	3	4	5
Not Important			Very High Importance	

Local	National	Global

13 - Would you pay extra for products with environmental benefits? Yes/No
If yes, indicate percentage of total product cost. .... %

14 - Are you willing to participate in product return schemes similar to those presently available for glass and plastic containers? Yes/No/Don't Know

15 - Instead of initial outright purchase would you be willing to rent these products? Yes/No/Don't Know

16 - Instead of initial outright purchase would you be willing to lease these products? Yes/No/Don't Know

17 - Would you like companies to provide information on the environmental characteristics of their products? Yes/No/Don't Know
If yes, are there any specific issues you would like them to cover?..

18 - Whose role should it be to push environmental issues?

Government	Producers	General Public
Environmentalists	Other	

19 - Whose role is it to decide the importance of environmental issues?

Government	Producers	General Public
Environmentalists	Other	

20 - Do you think that legislation is required to ensure these products are designed for the environment? Yes/No/Don't Know
If yes, are there any specific issues you would like the legislation to cover?..

C Life Cycle Participant Groupings

21 - Everyone has a role to play in the life cycle of computers and peripheral products, whether it's as a designer or a supplier or an environmentalist or other. In the following list (Table 1) tick one grouping which best categorises your role along with being a product user/consumer and a member of the general public. If you feel that none of the other groupings matches your role tick either product user/consumer or a member of the general public.

Table 1

No	Life Cycle Participant Grouping Roles
1	Marketing/Sales Personnel
2	Materials Expert
3	Product Designer/Developer
4	Purchasing Specialist
5	Manufacturing/Process Personnel
6	Packaging
7	Supplier/Sub-contractor
8	Distributors/Shipping
9	Product User/Consumer
10	Member of General Public
11	Service/Maintenance Specialist
12	End-of-Life Asset Management
13	Government
14	Environmentalist
15	Other (Please Specify)

D Product Requirements

22 - There is no single definition of the key requirements of computers and peripheral products. Taking the role you identified in Question 21 list on the provided space (Table 2) what you consider as the key requirements of the products you are familiar with.

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

Then, using Scale A weight the requirements in terms of overall importance.

Table 2

Product Requirements	Weight

E **Environmental Considerations**

23 - There is no single definition of the key environmental considerations for computers and peripheral products. Taking the role you identified in Question 21 list on the provided space (Table 3) what you consider as the key considerations for the products you are familiar with. Then, using Scale A weight them in terms of overall importance.

Table 3

Environmental Considerations	Weight

---- End of Questionnaire ----

Type No. 2: Used in 'SURVEYS B, C, F, G & L'

1 - Identify, and tick one of the following groupings which best categorises your role/position in the life cycle, from market to end-of-life, of the product group being reviewed. If your role applies to a specific product or product family please indicate;

Product / product family: ....

No	Life Cycle Participant Grouping Roles
1	Marketing/Sales Personnel
2	Materials Expert
3	Product Designer/Developer
4	Purchasing Specialist
5	Manufacturing/Process Personnel
6	Packaging
7	Supplier/Sub-contractor
8	Distributors/Shipping
9	Product User/Consumer
10	Member of General Public
11	Service/Maintenance Specialist
12	End-of-Life Asset Management
13	Government
14	Environmentalist
15	Other (Please Specify)

2- Taking the role/position you identified in Question 1, please weight the relative importance of the following environmental categories using the following scale:

0	2	4	6	8	10
Not Important				Very High Importance	

Energy consumption of product during usage	
Recycleability of product	
Material & Component issues, i.e. standardisation	
Quality & Reliability during usage	
Health & Safety during usage	
Human Factors (Ergonomics) during usage	
Physical Properties, i.e. weight, size etc.	
Service issues, i.e. ease of access parts for repair etc.	
Environmental Manufacturing issues, i.e. waste and pollution etc.	
Features/Functionality, i.e. speed, adaptability etc.	
Sustainable, i.e. self-sustaining, satisfying real needs of consumers	
Cost of product, i.e. to purchase and operate	
Recycleability of packaging	
Aesthetics of product, i.e. visual appearance etc.	
Issues associated with product disposal	
Resource consumption during usage	
Shipping & Storage issues	
(Other) Manufacturing issues, i.e. cost, ease of assembly, etc.	
Multiple Life Cycle issues, i.e. remanufacture and reuse of product	

---- End of Questionnaire ----

Type No. 3: Used in 'SURVEYS D, H & I'

A **Personal Details**

A1 - Gender:

Male		Female	

A2 - Nationality: ....

A3 - Research Area/Expertise:...

A4 - Research Industry/Product(s): ....

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

B General Environmental Information

B1 - Using a scale going from 1 (not important) to 3 (medium importance) to 5 (very high importance) indicate your degree of concern with environmental issues at each level.

Local	National	Global

B2 - How many years ECD related experience do you have? ....

B3 - Whose role should it be to push/drive environmental issues? Select one only.

Government	Producers	General Public
Environmentalists	Other	

B4. - Whose role is it to decide the importance of environmental issues? Select one only.

Government	Producers	General Public
Environmentalists	Other	

C Specific Environmental Information

C1 - A range of stakeholders that included users, designers and asset managers generated the list of key environmental categories (Table 1 below). On Table 2, please complete the following stages:

- Using Table 1, individually select the 'Top 8' environmental issues for your assigned product. You do not have to write them in order of importance.
- As a group come to a consensus on the 'Top 5' environmental issues. Again, you do not have to write them in order of importance.
- Individually weight the 'Top 5' issues in terms of overall importance using Table 3.
- As a group come to a consensus on the 'Top 5' weightings.

Table 1: Key Environmental Issues

a	Energy consumption of product during usage
b	Recycleability of product
c	Material & Component issues, i.e. standardisation
d	Quality & Reliability during usage
e	Health & Safety during usage
f	Human Factors (Ergonomics) during usage
g	Physical Properties, i.e. weight, size etc.
h	Service issues, i.e. ease of access parts for repair etc.
i	Environmental Manufacturing issues, i.e. waste and pollution etc.
j	Features/Functionality, i.e. speed, adaptability etc.
k	Sustainable, i.e. self-sustaining, satisfying real needs of consumers
l	Cost of product, i.e. to purchase and operate
m	Recycleability of packaging
n	Aesthetics of product, i.e. visual appearance etc.
o	Issues associated with product disposal
p	Resource consumption during usage
q	Shipping & Storage issues
r	(Other) Manufacturing issues, i.e. cost, ease of assembly, etc.
s	Multiple Life Cycle issues, i.e. remanufacture and reuse of product

Table 2: Study Worksheet

Top 8	Top 5	Individual Weighting	Group Weighting

Table 3: Weighting Scale

0	2	4	6	8	10
Not Important			Very High Importance		

C2 - A range of stakeholders generated the list of key environmental issues (Table 1). It is intended to use the list in qualitative ECD tools. As a group and using your wide range of experience tick the box in the following tables which you feel is most appropriate for this list of key environmental issues.

Table 4

the **list** is specific to one industry		applicable to a range of industries		generic and applicable to all industries	

Table 5

the **list** is specific to one product		applicable to a range of products		generic and applicable to all products	

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

C3 - Using the sustainable needs scale in Table 7, firstly as an individual and then through group consensus how would you rate the need for your assigned product now and in 10 years time? Complete Table 6.

Table 6

	Individual	Group
Now (1999)		
Future (2009)		

Table 7: Sustainable Needs Scale

0	2	4	6	8	10
Not Required			Vital for Maintaining Life		

C4. - As a group, come to a consensus on how many years you would ideally expect the product to be used for in its intended function. If applicable, include second or third lives through remanufacture, resale and reuse (Table 8).

Table 8: Life Scale (Years)

First Life	Secondary Life	Third Life

C5 - As a group, come to a consensus on the importance of the following stakeholders (Table 10) in identifying and weighting the key environmental issues for your product? Use the scale provided in Table 9.

Table 9: Weighting Scale

0	2	4	6	8	10
Not Important				Very High Importance	

Table 10: Key Stakeholders

1	Marketing/Sales Personnel
2	Materials Expert
3	Product Designer/Developer
4	Manufacturing/Process Personnel
5	Packaging
6	Distributors/Shipping
7	Product User/Consumer
8	Member of General Public
9	Service/Maintenance Specialist
10	End-of-Life Asset Management
11	Government
12	Environmentalist

C6 - As a group, and using the scale in Table 9, come to a consensus on the importance of each of the following life cycle stages (Table 11) in the environmental impact of your product?

Table 11: Life Cycle Stages

Market		Packaging	
Materials		Usage	
Design		Service / Repair	
Manufacturing		End-of-Life	
Distribution			

C7 - As a group, and again using the scale in Table 9, come to a consensus on the importance of each of the following end-of-life stages (Table 12) in the environmental impact of your product?

Table 12: End-Of-Life Stages

Product Collection		Recycle	
Product Storage		Incineration	
Reuse		Shred & Compact	
Remanufacture		Landfill Disposal	

C8 - As a group, come to a consensus on what the top 2 to 3 environmental issues for your product will be in the next 10 years? You do not have to write them in order of importance

Table 13: Top Environmental Issues

D Eco-design Influences

D1 - As a group, tick the 3 Stakeholders in Table 14 that will have the greatest influence on ECD issues over the next 10 years.

Table 14: Key Stakeholders

1	Marketing/Sales Personnel
2	Materials Expert
3	Product Designer/Developer
4	Manufacturing/Process Personnel
5	Packaging
6	Distributors/Shipping
7	Product User/Consumer
8	Member of General Public
9	Service/Maintenance Specialist
10	End-of-Life Asset Management
11	Government
12	Environmentalist

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

D2 - As a group, come to a consensus on what 2 to 3 factors will have the greatest influence on ECD over the next 10 years? You do not have to write them in order of importance.

Table 15: Eco-design Influences

D3 - Finally, individually decide what 2 to 3 factors currently have the greatest influence on your ECD opinions. You do not have to write them in order of importance.

Table 16: Product Influences

---- End of Questionnaire ----

TYPE NO. 4: Used in 'SURVEY E'

1 - Identify one of the following groupings which best categorize your role/position in the life cycle, from market to end-of-life, for electromechanical consumer durable devices. If your role applies to a specific product or product family please indicate.

Product / product family: ....

1	Marketing/Sales Personnel
2	Materials Expert
3	Product Designer/Developer
4	Purchasing Specialist
5	Manufacturing/Process Personnel
6	Packaging
7	Supplier/Sub-contractor
8	Distributors/Shipping
9	Product User/Consumer
10	Service/Maintenance Specialist
11	End-of-Life Asset Management
12	Government
13	Environmentalist
14	Other (Please Specify)

2. Taking the role/position you identified in 'Question 1' what do you see as the key environmental considerations, i.e. energy, ergonomics, emissions, etc? Weight the considerations using the provided 'weighting scale'.

Weighting Scale

1	2	3	4	5
Not Important			Very High Importance	

Environmental Consideration	Weight
1	
2	
3	
4	

3 - Taking the role/position you identified in 'Question 1' what are the key requirements, i.e. cost, performance, functionality, etc? Weight the requirements using the provided 'weighting scale'.

Requirement	Weight
1	
2	
3	
4	

---- End of Questionnaire ----

Type No. 5: Used in 'SURVEY I'

Company: ______________________________

Job Title: ______________________________

1. Taking your role as a ________________, please weight the relative importance of each of the following life cycle stages in terms of the environmental impact of 'Personal Computers and Peripheral Devices', using the following 'weighting scale'

Weighting Scale (0 – 10)

0	2	4	6	8	10
Not Important			Very High Importance		

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

Weight	Life Cycle Stage
	Design (Include. market, materials and packaging)
	Manufacture
	Distribution
	Usage
	Service
	EOL Disposal (Include. collection, storage, incineration, shredding, compaction and landfill)
	Multiple Life Cycle (Include. collection, storage, re-use, remanufacture and recycling.

---- End of Questionnaire ----

Type No. 6: Used in 'SURVEY J'

Background Details

1 - Title: Mr. Mrs Ms. Dr. Other....

2 - Gender: Male Female

3 - Name of organization you are employed by: ....

4 - Job Title: ....

5 - Key EOL Products: ....

Key Questions

6 .- Can you please identify the key EOL routes for typical electromechanical products, i.e., photocopiers, fax machines, keyboards, televisions etc?

7 - Can you please identify the key EOL levels for typical electromechanical products, i.e.. photocopiers, fax machines, keyboards, televisions etc?

8 - Can you please identify the key criteria that should be applied in the design of electromechanical products to ensure optimum EOL asset management?

9 - Can you please discuss your role in ECD and how you see it progressing over the next 5 to 10 years?

10 - Can you please suggest some other key stakeholders in EOL Asset Management. How do you see their roles progressing over the next 5 to 10 years?

---- End of Questionnaire ----

Type No. 7: Used in 'SURVEY K'

A. Background Details

A1 - Name: ....

A2 - Organisation: ....

A3 - Location: ....

A4 - Does your company have someone designated to be responsible for environmental issues? Yes/No

B. Product Data

B1 - What type of sales contracts do you offer?

Product	Outright Sale (Cash) %	Lease %	Rent %
Copier			
Fax			

B2 - How often, on average, do you service a:

a) Photocopier? ....

b) Fax machine? ....

B3 - What is the average life-span of a:

a) Photocopier? ....

b) Fax machine? ....

C. Legislation

C1 - On a scale of, 0 = Not Familiar to 4 = Very Familiar, how familiar are you with the pending take-back legislation (waste from electronic and electrical equipment directive)?

C2 - What do you consider will be the main effects of 'take-back' legislation on your business?

C3 - How is your company planning to countermeasure the take-back legislation? Are you taking a proactive stance?

D. Collection

D1 - How do you collect the machines? Do you use external agents, 3rd parties for collection?

D2 - Why did you adopt the current collection system?

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

D3 - Do the clients and/or other parties share the collection costs? Yes/No; If yes, how?

D4 - What is your main motivation for collecting used products?

D5 - Do you actively promote collection systems? Yes/No; If yes, how?

E. Take-Back & Recovery Data

E1 - Can you please provide your approximate take-back and recovery figures, in units, for last year.

Product	Return	Refurbish	Scrap	Trade -Price
Copier				
Fax				

E2 - Do you expect these figures to increase over the next few years? Yes/No

E3 - Do you have any suggestions for optimisation of the product EOL?

E4 - Are you familiar with current resource recovery methods? Yes/No.
For example, do you know what happens to your electronic waste?

E5 - Are you familiar with current resource recovery and EOL asset management companies? Yes/No

F. Market Requirements

F1 - Are customers demanding 'green' products? Yes/No

F2 - In your opinion is this an increasing area of interest amongst consumers? Yes/No

F3 - What types of 'green' considerations are being specified? Yes/No

F4 - Which requirements are perceived by potential customers to add the highest value, i.e. cost, performance, energy etc?

G. Remanufactured Products

G1 - Do you offer remanufactured products to your customers? Yes/No

G2 - What is the preferred method of sale for remanufactured products?

G3 - What kind of terminology do you use for 'remanufactured' products, i.e. re-manufacture, re-condition, re-furbish, repair, rebuilt, etc?

G4 - How often is a product remanufactured?

G5 - What is the end user's perception of these products?

G6 - What are your main reasons for offering 'remanufactured' products, i.e. customer request on environmental consciousness, customer request on cost, your environmental policy, regulations / laws, profits, etc?

G7 - Do you have separate management for your 'remanufacture' products marketing, i.e. serial number, bar coding, product labels etc? Yes/No

G8 - What is your idea of 'remanufacture' product price acceptance level?

Definition	Price Level
Brand New	100
Remanufactured	

G9 - What is your 'remanufacture' product marketing strategy, i.e., target certain companies, offer as cost-effective as possible. etc?

---- End of Questionnaire ----

Type No. 8: Used in 'SURVEY K'

Background Details

1 - Title: Mr. Mrs Ms. Dr. Other....

2 - Gender: Male Female

3 - Organization: ....

4 - Job Title: ....

5 - Key Products/Services: ....

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

Key Questions

6 - Can you please give your views on EOL asset management. Aspects to discuss could include: Market demand for second-hand OA equipment, predictions on growth of re-manufacturing industry for OA equipment and other electromechanical products over the next 5 to 10 years, EOL asset management categories and methods, collection, benefits of take-back, etc.

7 - Can you please give your views on re-manufacturing? Aspects to discuss could include: Product requirements that have caused the use or acceptance of re-manufacturing in the OA industry, details of established recovery and re-manufacturing facilities, reasons for offering re-manufactured products, re-manufacture stages, price issues, sales to trade, etc.

8 - Can you please give your views on MLC considerations. Aspects to discuss could include key factors that affect take-back and MLC, suggestions or recommendations for companies to countermeasure the situation and possible future activities, etc.

9 - Can you please give your views on various collection issues associated with EOL OA products? Aspects to discuss could include: collection methods, collection options, funding, present collection situation, future forecasts, laws on which collection is based and their predicted effect, suggestions for collection and treatment.

10 - Can you please give your views on various other issues. Aspects to discuss could include; role of stakeholders, changes you foresee in the future as a result of environmental legislation, suggestions or recommendations for companies to countermeasure the situation and possible future activities, points of direction, previously completed surveys and forecasting studies, terminology, case studies etc.

---- End of Questionnaire ----

Appendix A: Sample Questions from Questionnaires, Informal Interviews & Focus Group / Key Contacts

KEY CONTACTS

Many of these contacts have left their respective organisations since initial communication was made. The email address, or telephone number, and organisation details, refer to the where they are currently employed. Although these details were verified prior to publication, the author can make no guarantee as to the currency, and accuracy of them.

Dr. E. Dewberry (e.dewberry@gold.ac.uk), Goldsmiths College, University of London, U.K.

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Dr. M. Simon (m.simon@shu.ac.uk), Sheffield Hallam University, U.K.

Dr. T. Bhamra (t.bhamra@cranfield.ac.uk), Cranfield University, U.K.

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Mr. B. Atkin (brian.atkin@mail.panasonic.co.uk), Environmental Affairs Manager, Panasonic, U.K.

Mr. B. Warren, (bwarren@itw.ie), Sales & Marketing Manager, Electronic Recycling, Ireland.

Mr. C. Ciantar (cciantar@bournemouth.ac.uk), Bournemouth University, U.K.

Mr. C. Voute (Tel: +44-(0)171-2369541), Recycling and Waste Control Officer, Corporation Of London Recycling Office, U.K.

Mr. D. Collins (Dan_Collins@dell.com), Product Engineer, Dell Computers, Ireland.

Mr. D. Foley (David.Foley@GBR.XEROX.COM), Environmental Researcher, Xerox (Europe) Ltd., U.K.

Mr. D. Tsuda (tsuda@apple.com), Environmental Engineering Strategies Manager, Apple Computer, California, U.S.A.

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Mr. J. Chiodo (joseph.chiodo@brunel.ac.uk), Brunel University, U.K.

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Mr, J. Hayes, (+353-(0)23-45333), Production Manager, PSK Ltd., Ireland.

Mr. J. Rook (j.rook@ikon.com), Manager, Ikon European Re-manufacturing Ltd., U.K.

Mr. N. de Caluwe (Nils.de.Caluwe@philips.com), Philips CFT - Philips Environmental Services, The Netherlands.

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Mr. I. Karttunen (Ilkka@BUSSMANN.CO.UK), Engineer, Bussman, U.K.

Mr. R. Pender (Tel: +353-(0)1-8225014), Plant Manager, Mann Organization (Ireland), Ireland.

Mr. S. Lee (S.A.Lee@sheffield.ac.uk), Environmental Product Design Advisor, EBN, University of Sheffield, U.K.

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Ms. E. Jones (EliesJones@compuserve.com), Brunel University, U.K.

Ms. V. Lofthouse (v.a.lofthouse@cranfield.ac.uk), Cranfield University, U.K.

Ms. V. William (Intex007@aol.com), Environmental Affairs, Intex Group, U.K.

Ms. W. Ijomah (w.ijomah@plymouth.ac.uk), University of Plymouth, U.K.

Prof. C. Coggins (p.c.coggins@sheffield.ac.uk), Director, Waste Management & Technology Centre (WAMTEC), University of Sheffield, U.K.

Appendix B: ECD Methodology Guidelines

ECD CATEGORY GUIDELINES

CATEGORY	**MATERIAL ISSUES**
STAGE	MANUFACTURING

Key Stakeholders: Materials Expert, Product Designer, Manufacturing Personnel, Service Personnel, EOL Asset Manager.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of material and component issues?

Generic Questions

Is it a mono-material or multi-material product?
Is it a mono-part or multi-part product?
Does the product consider material, chemical and component source, production, selection, standardization, and minimization?
Does the product consider the use of non-toxic, recycled, organic or biodegradable options?

Prototyping Material

Consider the environmental impact when developing prototypes. Use 3D concept images or animation for initial market testing and where possible use recyclable materials (i.e. wood, paper).

Supplier Policy

Ensure suppliers have an environmental policy and have, or are in the process of setting up, an active ECD system. Include environmental considerations in a formal approval process for materials and components and their suppliers' i.e. use a template.

Material, Chemical and Component Selection

Refer to recycling category, disassembly analysis and packaging recycling category.
Standardize and reduce the number of items and materials used in product (minimization through use of snap fits and integration of components).
Implement material selection tools that include environmental criteria.
Use realistic specification of material requirements and minimize part numbers.

Material, Chemical and Component Selection

Don't mix polymer types, identify additives, and where possible use lower grade, recyclable or recycled materials.
Consider biodegradable materials to reduce disposal problems (This may require a change in perception by the industry and its customers).
Material selection should include consideration of properties for EOL recovery, i.e. ease of contamination, cleaning and density etc.
Minimize the use of scarce and specialized materials and minimize the use of materials whose processing is energy-greedy or produces toxic by-products.

Avoid using incompatible spray paints, coatings, plating or stickers.
Where special accents or shadow effects are desired in-molded textures and reliefs - advanced ink diffusion techniques can be an alternative.
Reduce number of permanent inserts. If possible avoid metal inserts. Where metal inserts are required they should be ferrous. Use of break out area's where inserts are required.

Standardized Identification

Where possible, avoid added paper and metal labels. Environmentally sensitive options include molded-in legends and 'pop-in-pop-out' labeling.
Where non-compatible labeling is necessary use water-soluble adhesive types. Labeling should be relevant, accurate and not misleading.
Color code parts for one product-recycling stream.
Bar coding information should be added through in-molded relief or laser marking.

Circuit Boards and Components

Group the high and low value components in separate areas of the circuit board and make sections of the board easy to break off.
Any hazardous components should be easy to identify and remove and should, where possible be contained and made harmless.
Apply functional selection in component sourcing, considering minimization and miniaturization.

Emission & Susceptibility to Interference, Radiation and Electrostatic Discharge.

Minimize emissions and then add protection.
Concentrate on a local level before total, use metal or film laminates.
Try to avoid coatings, i.e. solvent-based paint, vacuum metallized and plated.
Electrostatic discharge materials should be recyclable or recycled materials.

Useful Additional Approaches:
'Closing Materials Cycles': Extract as few rare materials as possible - use materials as long as possible through reusing parts and recycling materials
Use an industry recognized 'Material Selection Software' package or 'Quantitative LCA Software' package.
Use an industry recognized Material Selection Checklist.

Appendix B: ECD Methodology Guidelines

CATEGORY	ENVIRONMENTAL MANUFACTURING
STAGE	MANUFACTURING

Key Stakeholders: Product Designer, Manufacturing Personnel.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of environmentally conscious manufacturing?

Generic Guidelines

Does the production process consider waste minimization, recycling, power source, pollution, resource use, choice of processes, i.e. printing.

Generic Guidelines on Processes

Where possible incorporate reversible manufacturing stages.
Where possible eliminate high environmental impact manufacturing processes such as insertion, sequencing and soldering.
Consider common environmental impacts, i.e. emissions, occupational health & safety, human factors, waste, resource consumption and energy loss.
Use laser printing where possible.

Generic Guidelines on Molding

Consider part design - use realistic specifications.
Avoid family tooling and minimize the tool runner system, sprue length and use a hot runner system where feasible
Use a closed loop granulation system, considering the weight of material for feeding.
Where possible specify regrind, i.e. minimum 30%, with correct wall thickness (May require a change in perception of regrind by the industry and its customers).
Use mold flow analysis to minimize tool trials.
Ensure accurate forecasting of sales volume (Over production shortens tool life, results in additional maintenance and requires additional storage).
Consider the order size for distribution. Aim for full loads on all deliveries, using reusable packaging for transporting finished goods.
Consider material return loops, minimize material types and where possible specify recyclable or biodegradable materials.

Useful Additional Approach:
'Environmentally Manufacturing Indicator': Assumes that all environmental decisions can be brought back to one category - environmental manufacturing.

CATEGORY	MANUFACTURING ISSUES (OTHER)
STAGE	MANUFACTURING

Key Stakeholders: Product Designer, Manufacturing Personnel.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of manufacturing?

Generic Guidelines

Does the production process consider localized manufacture, labor issues, choice of manufacturing processes and equipment, design for assembly and manufacture, machine safety and reliability and set-up costs?

Useful Additional Approach:
Design for Assembly and Manufacture Tools.

CATEGORY	SHIPPING & STORAGE
STAGE	DISTRIBUTION

Key Stakeholders: Product Designer, Distribution Personnel, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of shipping and storage?

Generic Guidelines

Does the product distribution consider the type of transport, storage time, order size etc.?
Consider the storage time of stock and finished goods, accurate forecasting, goods made-to-order, order size, and fixed delivery runs.
Consider the size, shape and packaging method, ease of stacking and storing and reduction in volume of materials such as polystyrene.

Useful Additional Approach:
'Shipping & Storage Indicator': Assumes that all environmental decisions can be brought back to one category - shipping and storage.

Appendix B: ECD Methodology Guidelines

CATEGORY	**PACKAGING RECYCLING**
STAGE	DISTRIBUTION

Key Stakeholders: Packaging Designer, Distribution Personnel, User, EOL Asset Manager.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the packaging rate in terms of ease of recycling?

Generic Questions/Guidelines

Does the packaging use recyclable materials?
Refer to 'material issues' category.
Consider how packaging life span can be extended or the material can be recovered more efficiently - change 'throwaway-image'.
Consider all the key environmental criteria over every stage of the packaging life cycle. Examine the entire environment the package is working in; look at the whole process of getting a package and product out of the factory.
Consider EOL collection methods, i.e. return by post.
Use recycled, non-bleach-packaging material. Avoid using foam-packaging inserts and have all print in one color only. A reduced print area can give an environmentally friendly image. The print information themes could be picked up through the display environment in places such as shopping centers. Replace expanded polystyrene with biodegradable option, i.e., starch. Consider novel packaging techniques, i.e. air packaging, reusable trolleys etc. Consider options such as multi-packaging and integral packaging. Consider using only one material and reduce materials - these can be up to 60% of the overall packaging cost.
Investigate if product environmental benefits can be displayed on the product housings or packaging?
Ensure the supporting documentation is on recycled paper
Examine the current packaging testing procedure and transportation and storage requirements.

Useful Additional Approach:
'Packaging Recycling Indicator': Assumes that all environmental decisions can be brought back to one category - packaging recycling.

STAGE	***USAGE***

General Usage Guidelines

Consider typical daily usage (i.e. % breakdown of transactions).
Provide instructions on optimum usage of product(s).
Ensure product complies with any relevant standards, i.e., quality and reliability, health and safety and human factors.
Consider the life span of the product?

Useful Additional Approaches:
'Environmental Marketing': The market determines the environmental criteria.
'Environmental Legislation': Selection of environmental criteria is determined by existing and expected legislation.
Burden per unit function: Consider in terms of number of lives.
'Conceptual': Questions the product concept from an environmental perspective and in the context of sustainable development.
Reverse LCA: This analysis involves questioning the need for the product, its features and functions.
Design an 'Ideal' sustainable concept.

CATEGORY	**SUSTAINABLE**
STAGE	USAGE

Key Stakeholders: Product Designer, User, Government, ECD Expert.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of sustainability?

Generic Questions/Guidelines

Does the product play an active role in achieving the long-term vision of sustainability and a sustainable society?
How does the product rate on the sustainable needs scale below?
Product features that consider the needs of the present without compromising the ability of future generations can be termed 'Sustainable'.
Consumption goes complete circle, materials are renewable and the product has a further use. Features include self-sustaining, satisfying a real need (usefulness), beneficial to user, service intensity, quality of life, etc. A radical change in behavior and a reduction in consumption of resources and energy characterize sustainable products. Sustainable products must generate capital for future generations to offset their use of non-renewable resources.
Sustainable strategies include dematerialization, reduction, service-products, product life extension and product or component cycling.

Consider Usage Eco-Efficiency

An eco-efficient product oriented service, i.e. through building in a service/maintenance contract.
An eco-efficient use oriented service, i.e. through offering the products on a rental or lease basis or implementing a multi-user sharing option.
An eco-efficient need oriented service, i.e. through satisfying the need when required.

Sustainable Needs Scale

0	2	4	6	8	10
Not Required			Vital for Maintaining Life		

Appendix B: ECD Methodology Guidelines

CATEGORY	**PRODUCT ENERGY**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - If the product is energy consuming, how well does it rate in terms of energy consumption during usage?

Generic Questions/Guidelines
Does the product consider the power source and power down modes?
Ensure product complies with any energy consumption standards, i.e. energy star.

Useful Additional Approach:
'Energy Indicators': Assumes that all environmental decisions can be brought back to one value - energy.

CATEGORY	**PHYSICAL PROPERTIES**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of physical properties?

Generic Questions/Guidelines
Does the product consider space, size, compactness, mass, weight, height, volume and ease of movement (portability)?
Consider the approximate dimensions of the product.

Useful Additional Approach:
'Physical Properties Indicator': Assumes that all environmental decisions can be brought back to one category - physical properties.

CATEGORY	**USAGE RESOURCE CONSUMPTION**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - If the product is resource consuming, how well does it rate in terms of consumption of resources during usage?

Generic Questions/Guidelines
Does the product consider the use of resources such as water, ink, paper and other materials?
Avoid use of batteries. Otherwise provide a take-back system and/or recommend best EOL route to the customer.

Useful Additional Approach:
'Usage Resource Indicator': Assumes that all environmental decisions can be brought back to one category - usage resource consumption.

CATEGORY	**QUALITY & RELIABILITY**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of quality and reliability?

Generic Questions
Does the product consider warranty, life span, performance, accuracy, durability, robustness, redundancy time, customer issues and efficiency?

Useful Additional Approach:
'Quality & Reliability Indicator': Assumes that all environmental decisions can be brought back to one category - quality & reliability.

Appendix B: ECD Methodology Guidelines

CATEGORY	**HEALTH & SAFETY**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of health and safety?

Generic Questions
Does the product consider radiation, emissions, noise, heat, sharp edges, compliance with laws, and environmental health etc?

Useful Additional Approach:
'Health & Safety Indicator': Assumes that all environmental decisions can be brought back to one category - health & safety.

CATEGORY	**HUMAN FACTORS**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of human factors?

Generic Questions
Does the product consider ergonomics, usability, user environment, flexibility (i.e. catering for disabled) user friendliness and interface design?

Useful Additional Approach:
'Human Factors Indicator': Assumes that all environmental decisions can be brought back to one category - human factors.

CATEGORY	**FEATURES / FUNCTIONALITY**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of features and functionality?

Generic Questions
Does the product provide the required features and functions?
Does the product consider compatibility, standardization, versatility (i.e. configurable), adaptability, capabilities, task suitability, and speed?

Useful Additional Approach:
'Features/Functionality Indicator': Assumes that all environmental decisions can be brought back to one category - features/functionality.

CATEGORY	**PRODUCT COST**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of product cost?

Generic Questions
Does the product consider unit and operations cost, resale value, value (for money) and consumables?

Useful Additional Approach:
'Environmental Economic': All the environmental consequences of a product are translated into environmental costs.

CATEGORY	**AESTHETICS**
STAGE	USAGE

Key Stakeholders: Product Designer, User.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of aesthetics?

Generic Questions
Does the product consider visual appearance?
Does the product consider shape, proportion, balance, color, texture, geometry, structure and compactness?

Useful Additional Approach:
'Aesthetics Indicator': Assumes that all environmental decisions can be brought back to one category - aesthetics.

Appendix B: ECD Methodology Guidelines

CATEGORY	**SERVICE ISSUES**
STAGE	SERVICE

Key Stakeholders: Product Designer, User, Service Personnel, EOL Asset Manager.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of ease of service?

Generic Questions/Guidelines

Does the product consider maintainability, expandability, reparability, upgradeability, modular design and accessibility?
Consider design for repair, assembly/disassembly, identification and product complexity.
Increase visibility, accessibility and location of components. Reduce time taken to clean and service product.
Consider ease of de-soldering, re-soldering along with removal and replacement of surface mount components.
Consider issues such as a reducing component weight, number and type of screws and screw insert, wall thickness of threaded hole and type of thread.
Use clips instead of glue (for cable attachment).
Consider standardization of components and test equipment (manufacturer, retailer and service center).
Make failure details and failure history available.
Relate product warranty to date of sale rather than date of manufacture (Otherwise shredding for disposal may be the most cost-effective option).
Consider reusable packaging and methods of stacking for transporting goods.
Consider distribution chain, location of service center, storage and type of transport.
Consider EOL asset management of waste packaging and non-repairable items.

Useful Additional Approach:
'Service Indicator': Assumes that all environmental decisions can be brought back to one category - service.

CATEGORY	**PRODUCT RECYCLING**
STAGE	EOL

Key Stakeholders: Product Designer, EOL Asset Manager.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of ease of recycling?

Generic Questions/Guidelines

Does the product consider disassembly, ease of shredding, cleaning and recycling?
Refer to 'material issues' category and to disassembly analysis.
Supply parts, material & component lists and, where possible, design specifications (& % by weight).
Consider component location, ease of sorting, separating, cleaning, compacting and shredding components and products and EOL logistics.

Useful Additional Approach:
'Recycling Indicator': Assumes that all environmental decisions can be brought back to one category - recycling.
Design for disassembly tools and techniques.

CATEGORY	**DISPOSAL ISSUES**
STAGE	EOL

Key Stakeholders: Product Designer, EOL Asset Manager.

Key Questions:
Weighting - How important is this category in the context of the product being assessed and relative to the other categories?
Scoring - How well does the product rate in terms of disposal?

Generic Questions/Guidelines

Does the product consider safety at EOL, landfill options and safe disposal?
Consider EOL logistics and valorization through heat recovery. Take account of air emissions, heat value, available consumer, ash toxicity etc.
Refer to 'material issues' category.
Provide safe disposal instructions or an EOL disposal service?

Useful Additional Approach:
'Hazardous Waste': Focuses on prevention of toxic waste in the product life cycle. Provides designer with a list of toxic materials
'Disposal Indicator': Assumes that all environmental decisions can be brought back to one category - disposal.

Appendix B: ECD Methodology Guidelines

LIFE CYCLE STRATEGY GUIDELINES

Key Stakeholders:
Marketing, Materials Expert, Product Designer, Manufacturing Personnel, Management, User, Service, EOL Asset Manager, ECD Experts.

STEP 1: GENERAL GUIDELINES

Multiple life cycle products involve extended lives through secondary markets. They can involve manufacturers buying back products; suppliers/molders buying back components and materials; users buying second-hand products. Consider the product in terms of each of the following questions.

General Questions

Should the product, component or material be single or multiple life?
What should the life span be (years)? Consider an 'ideal' and 'actual' scenario.
How many lives should the product, component or material have (1,2,3, ...)? Consider an 'ideal' and 'actual' scenario.

General Multiple Life Cycle Questions

How well does the product, components and materials rate in terms of the following multiple life cycle issues?
Can the product consider design for reuse, 'updgradeability', 'downgradeability' and 'modularity'?
Can the product (or some product item) be designed so that it has a useful secondary purpose?
Can the product be part of a family and not a one-off design?
Can the life of the product, component or material be extended?

Co-operation Questions

Can you work closely with an EOL asset management company to ensure viability but also consider security and confidentiality?
Can a parts, material & component lists and, where possible, a design specifications (& % by weight) be supplied?
Can the testing details (for components and system) and details of re-programmable chips be supplied?
Can the product's life be extended through resale? (Implications for the reputation/liability of the manufacturer.)
Can the product be 'rebadged' (white box brand name) by an EOL asset manager?
Can the product incorporate quick removal labeling; i.e. labeling that can be removed by grinding or covered over for 'white box goods' branding?

Consider the product in terms of the appropriate EOL asset management recovery level for reuse, Figure B.1 to Figure B.3.

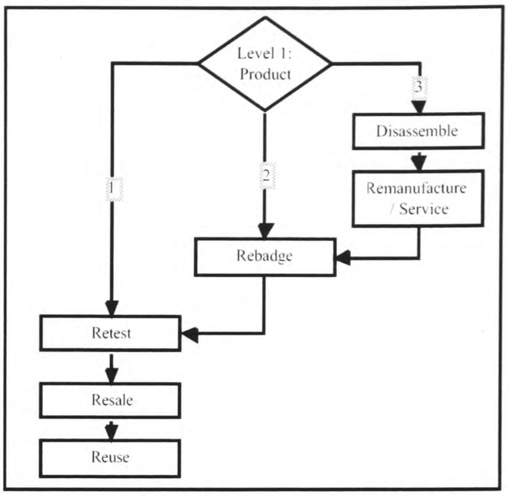

Figure B.1 EOL Level 1: Product Asset Management

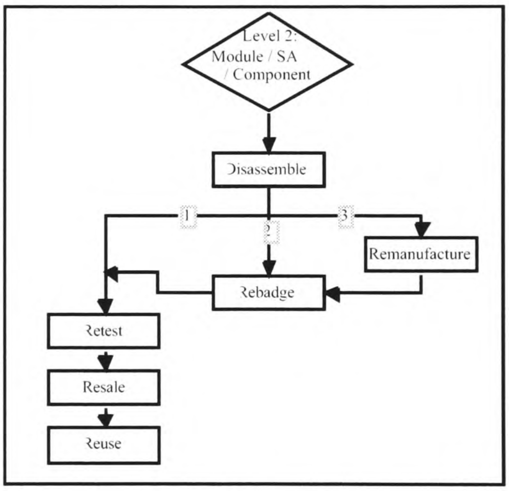

Figure B.2 EOL Level 2: Module/SA/Component Asset Management

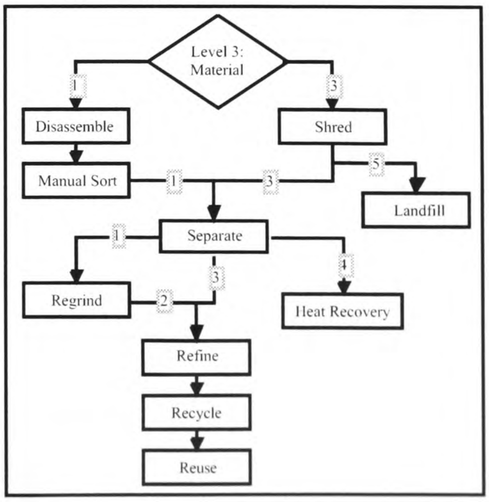

Figure B.3 EOL Level 3: Material Asset Management

Appendix B: ECD Methodology Guidelines

STEP 2: MULTIPLE LIFE CYCLE FACTORS

Consider the product in terms of each of the following six factors.

Cost	Will it be cost effective for the product to have a MLC? Consider issues such as profit, economy and target market.
Awareness	Is the awareness level sufficient for a MLC product? Consider customer perception, environmental awareness, education and environmental organizations. (Note: On purchase, PC users require environmental information on the products, and are prepared to pay extra for products with environmental benefits).
Product Issues	Is the product suited to a MLC? Consider new technology, technology advances, quality, reliability, function, upgrading, guarantees, contamination, parts supply and servicing. Refer to the detailed list of product issues.
Legislation	Is the legislation favorable towards a MLC product? Does the industry use a recognized set of terminology for new and MLC products? Consider new and impending legislation, government policies, and the use of standardized terminology.
Infrastructure	Is the infrastructure in place for a MLC product? Consider funding, collection, storage availability and globalization. Refer to the detailed list of collection options.
Stakeholder Co-operation	Are the mechanisms in place for stakeholder co-operation? Consider closed-loop co-operation with a range of key stakeholders.

Infrastructure - Collection Options

Consider the following collection options for the product.

1	Through existing waste collection infrastructure, i.e. via the local authorities or municipalities.
2	Through obliging retailers to accept products.
3	Manufacturers collect from the municipalities and carry out any subsequent sorting and recycling.
4	Manufacturers/dealers accept the products from users. Lease agreements would make collection easier as the manufacturers/dealers have control over the machines. The collection could be linked with the delivery of new machines as the infrastructure is already in place, i.e. reverse distribution.
5	Through encouraging customers to return used products through offering a reduction when purchasing new ones.
6	Manufacturers set up their own collection systems for products and packaging.
7	Collection systems using 3rd party collection agencies, possibly in partnership with manufacturers.

Product Issues

Consider the product in terms of each of the following factors.

Burden Unit/function	Consider the effect of a long life or extended lives on energy and resource consumption during usage? Will an extended live have an adverse affect on these considerations?
Method of Sale	Is the product rented or leased or sold outright? Rental or leasal can facilitate EOL collection. (Note: PC users prefer outright purchase).
Product Price	What is the sale price? A low sale price makes a MLC less attractive to the consumer, although this is relative, and dependent on the state of the economy.
EOL Image	How do consumers perceive the EOL product? Do they perceive it as being reusable or disposable?
Service Frequency	How frequently is the product serviced? Products with high service frequency are frequently given a MLC through remanufacture.
Second-hand Demand	Is there a current demand for second-hand products? Is this expected to increase?
Second-hand Price	What is the current second-hand price? Does this price make it attractive to design the product for a MLC?
Second-hand Guarantee	What are the current second-hand guarantees? If a similar second-hand guarantee can be given then the product may be more suited to a MLC.
Second-hand Appearance	Does the product look okay at EOL? Products that keep their appearance are generally more suited to a MLC.
Reasons for offering products	What are the current reasons for offering these products second-hand? Do these reasons match the agenda of your company? Consider cost benefits, regulations, waste reduction, environmental policy, corporate image, and customer request on environmental consciousness.
Remanufacture Frequency	How often are these products currently remanufactured? This will provide information on the number of lives and life span.

Appendix B: ECD Methodology Guidelines

Acceptance of Re-manufacturing	Is re-manufacturing of this product currently widely accepted? Why?
Technology cycle	Consider the length of time before mechanisms supporting the main product functions become outdated. If this is short then a SLC may be the preferred option for the current design.
Wear-out cycle	Consider the length of time from product purchase until product no longer meets the original function. If this is short then a SLC may be the preferred option for the current design.
Design cycle	Consider the length of time between successive generations of a product. If this is short then a SLC may be the preferred option for the current design.

STEP 3: EOL REASONS

Consider the common EOL reasons below.

No.	***Reason***
1	Ever-increasing production favors less durability (Kostecki, 1998).
2	Managerial decision-making is biased towards single use (Kostecki, 1998).
3	Consumers have a preference for novelty (Kostecki, 1998).
4	Consumers are manipulated to consumer faster (Kostecki, 1998).
5	Rise in per capita income reduced consumer's concern with optimal use of products (Kostecki, 1998).
6	Product/service price ratio has changed to the disadvantage of the repair service and has reduced the life of products (Kostecki, 1998). The cost of repair may be higher than cost of replacing the product.
7	Technological progress continues to render products obsolete (Kostecki, 1998), for example, upgrading of product families resulting in compatibility problems, or new advances highlight shortcomings of products and customers phase out usage.
8	Difficulty in communicating the benefits of durability to the consumer (Kostecki, 1998).
9	Most used products have an image problem (Kostecki, 1998).
10	The systems of retake, re-marketing and re-manufacturing tend to be archaic and ineffective (Kostecki, 1998).
11	Social pressure, for example, customers demanding new styles, shapes and colors to 'stay in fashion'.
12	Failure to fulfill original need or end of useful life, for example, children's pram no longer required as all children have grown up.
13	Legislation, for example, new legislation highlights negative impacts of products and customers phase out usage.
14	Products are intentionally designed for applications that mean a very short life, for example, packaging and disposable blades. Some products are perceived as having short-term lives, a 'throwaway image'.
15	Supply of parts, for example, a manufacturer stops producing spare parts so the product becomes obsolete.

STEP 4: LEVELS OF FUNCTION

Consider three levels of function: primary, secondary and tertiary. Using a functional tree will assist in developing the levels of function.

1	Primary	Can the product be directly reused, i.e., reuse of television packaging in it original function?
2	Secondary	Can the product be reused in an application related to the original application, i.e., television ancillary device: stand, cover, etc?
3	Tertiary	Can the product be reused in an unrelated application, i.e., board game, dolls house, children play house, furniture, waste box, etc?

STEP 5: ROUTES

Consider the possible routes available: Service/Reuse/Remanufacture/Recycle (disassemble or shred)/Heat Recovery/Dispose

Service:	How well does the product rate in terms of ease of service? Refer to service category guidelines.
Reuse:	How suitable is the product for reuse?
Remanufacture:	How well does the product rate in terms of ease of remanufacture? Refer to service category guidelines.
Recycle (disassemble):	How well does the product rate in terms of ease of recycling through separation? Refer to disassembly analysis and recycling category guidelines.
Recycle (shred):	How well does the product rate in terms of ease of recycling through shredding? Refer to recycling category guidelines.
Heat Recovery:	How well does the product rate in terms of incineration for heat recovery?
Dispose:	How well does the product rate in terms of ease of disposal through landfill? Can the product be disposed safely? Refer to disposal category guidelines.

Appendix B: ECD Methodology Guidelines

Disassembly Analysis

How well does the product rate in terms of ease of disassembly? Consider time taken to disassemble main elements of product using the disassembly and value templates.

Consider the following factors:

Number of parts	What is the approximate number of parts, i.e. taken from bill of materials (BOM)? Are these parts suitable for a MLC? Can these be reduced in future designs?
Number of materials	The number of different materials used. Are these materials suitable for a MLC? Can the number be reduced in future designs?
Number of modules	The number of subassemblies that are physically detachable and preserve function. Are these subassemblies suitable for a MLC?
Cleanliness level (filthiness)	The amount of dirt or grime that hinders reuse or recycling. Will this hinder a MLC?
Hazards	Hazardous or unwanted materials that can contaminate components. Can the number be reduced in future designs?

General Design for Ease of Assembly/Disassembly Guidelines

Consider providing the EOL asset manager with any specials tool for EOL recovery, i.e. screws for security lid.
Prepare instructions for ease of disassembly, disassembly analysis, i.e., 'Disassembly Manual'.
Consider the development of disassembly lines.
Design for "top-down" vertical assembly, and 'chassis' or 'module' assembly.
Simplify the interface for reusable components

Fastening Guidelines

Minimize the number of added fasteners and if possible avoid metal fasteners. When applied they should be ferrous and easily accessible.
Where possible, integrate parts, use de-mountable parts (no solid fixings) and non-added part assembly, i.e. snap/push fits and other integrated fastening techniques, considering disassembly as well as assembly.
Where practical fixing and fasteners should be designed in compatible materials. When non-compatible items or irreversible connections are applied, 'predetermined break areas' should be designed-in.
Don't use adhesives, welding or heat-staking to join incompatible plastics. Where adhesives are unavoidable use compatible types or water-soluble types.
Make interconnection points and joints easily accessible.

EOL Value

Consider the product and its components to identify any potential EOL value if a secondary market can be established using the disassembly and value templates. Consider recycling value drivers, parts or materials with high profits that either drive recycling or reuse. One option is to increase component value for feasible disassembly and recovery.

STEP 6: FINALIZE THE LIFE CYCLE STRATEGY

Make a final decision on the life cycle strategy based on the previous 5 steps.

Appendix C: Publication Titles & Abstracts

PUBLISHED PAPERS

1. O' Connor, F., Youlden, P. and Blythe, D., An Eco-Design Concept Keyboard - A University - Industry Partnership, The Continuum of Design Education, Professional Engineering Publishing, U.K., pp. 249-253, (1999).

Eco-design education provides designers with the knowledge and tools to reduce and eliminate many of the worlds environmental problems. This paper examines one approach to eco-design education through collaborating with industry. A final year Product Design student was asked to develop an eco-design concept keyboard on behalf of Alps Electric Ltd. To simplify the design process it was decided to focus on a selection of criteria, which included ergonomics, modularity and ease of disassembly. This paper gives a brief overview of the student's conceptual work along with providing some feedback on the approach.

2. O' Connor F. and Blythe, D., Remanufacturing of Office Automation Equipment, *Proc. 15th International Conference on Production Research*, University of Limerick, Ireland, pp. 1699-1702, (1999).

The paper provides a brief overview of a study carried out on the asset management of office automation equipment in the U.K. The paper focuses on the collection and remanufacturing of copiers and fax machines, and gives a brief overview of the work of two major remanufacturing companies. Key legislative documents are discussed along with the current demand for recovered products, future forecasts and the key criteria for success in the implementation of remanufacturing practices.

3. ADEME, Product Design and Environment – 90 Examples of Eco-Design, ADEME, Paris, France, pp. 61, (1999).

Alps Electric Limited (ALIR) proactive environmental approach includes developing waste minimization programs and gaining certification to ISO 14000. A research agreement was drawn up with an eco-design team at the University of Glamorgan to examine the life cycle effects of a range of ALIR products. The product chosen for the initial eco-design study was a computer keyboard. An abridged Life Cycle Analysis was performed resulting in incremental design improvements. From this and other research a number of concepts were generated which met ALIR market requirements but also significantly reduced the environmental impact of the keyboard.

4. O' Connor, F., Blythe, D. and Phelan, P., Analyzing Environmental Issues – A Case Study of the Production of a Computer Component, *Engineering Designer Journal*, **September/October**, pp. 4-7, (1998).

Computer manufacturers are currently being faced with recycling regulations, impending product take-back, and other legislation, forcing them to analyse and reduce the environmental impact of their products and processes. Techniques such as quantitative Life Cycle Assessment (LCA) have been developed to examine the environmental burdens of products over their whole life cycle. Traditional LCA approaches are complex and problematical and fail to address other design requirements such as functionality and safety. Taking these factors into consideration, a number of alternative approaches have been proposed. Using an abridged life cycle analysis (ALCA) approach, this article recounts the results of a case study whose aim was to systematically analyse the major environmental issues associated with the production stages of a computer component. The ALCA approach used involved both quantitative and qualitative analysis of the key environmental issues and requirements using techniques such as flow diagrams, matrices and profiling. By consulting the major stakeholders at the production stage, the environmental criteria and the requirements under which the component could be analysed were identified. As a result, and with a view to a long-term modification of the production process, some potential improvements were identified. A summary of the results from the study is given along with conclusions drawn, and a brief discussion of planned further work.

5. O' Connor, F., Blythe, D., O' Sullivan, J. and Phelan, P., Initialization of an Environmental Philosophy: A Case Study of Alps Electric (Ireland) Ltd., *Proc. Business Strategy & the Environment Conference*, University of Leeds, U.K., pp. 168-173, (1998).

This paper outlines the business approach taken by Alps Electric (Ireland) Ltd., a computer peripheral division of the Alps Corporation, in their development of an environmental philosophy. In June 1993, the company issued a management charter to investigate and establish the threats and opportunities, which would be presented as a result of new and impending legislation in the area of electronic equipment and the environment. A top-down approach was implemented during the following years with the charter widened to include Environmental Management, Design for Environment and Sustainability. This has resulted in a number of opportunities for the company, including enhanced corporate image, reduced production, service and 'end-of-life' costs and preparation for legislation. Key stages included: setting up of an in-house Electronics Waste Disposal and Recycling Group; development of a Waste Management System; implementation of an Environmental Management System, including certification to ISO 14000; Environmental Performance Profiling through consulting the stakeholder; implementation of a Design for Environment program. This paper will outline some of the company's experiences from the initial charter through to the recent product case studies. The paper will go on to discuss future directions to assist in achieving the goals of a sustainable society. Finally, the paper will conclude with a review of this unique top-down approach, which has resulted in a deep-rooted environmental philosophy in the company over a five year period.

6. O' Connor, F., Blythe, D. and Phelan, P., Practical tools for Environmentally Conscious Design and Manufacture (ECDM), *Proc. 15th Irish Manufacturing Conference (IMC 15)*, Ulster of Ulster, U.K., pp. 213-221, (1998).

The Environmentally Conscious Design and Manufacture approach aims to reduce environmental impact during all stages of a products life cycle, from design through to end-of-life. This paper outlines the approach, and provides an overview of how it can be implemented using practical abridged life cycle analysis tools. These tools involve both quantitative and qualitative analysis of the key environmental issues. Life cycle stages are drafted initially on a flow diagram format, highlighting the major inputs and outputs. The key environmental criteria are then identified and weighted for matrix analysis through consulting the major stakeholders. This is followed by profiling of the key stages, and environmental criteria, so that potential improvements can be identified. Two practical examples of where the analysis tools have been tested using case studies at Alps Electric (Ireland) Ltd are referred to. The first study was carried out on the manufacture of an existing component, while the second study was carried out during the detail design stage of a product, which was being developed under a Concurrent Engineering system. A brief review of the results and conclusions drawn from using the tools are given, along with a discussion of implications and resulting opportunities.

7. O' Connor, F., Product Design for the Environment Education (PDE^2), *5th National Product Design Education Conference*, University of Glamorgan, U.K., (1998).

The majority of environmental problems which we face today, have been caused in one way or another by the production, use and disposal of products. One approach to reducing negative environmental impact is through Design for the Environment (DfE). Product Design for Environment Education (PDE^2) offers designers a real opportunity to affect the future in a positive way, by providing them with the knowledge and tools to reduce and eliminate these environmental problems. This paper defines DfE, and examines briefly how environmental issues can be integrated with traditional design considerations, through implementation as part of Simultaneous Concurrent Engineering structure. The paper then proceeds to examine PDE^2, through a pilot module, for product design students. The practical case study approach chosen involved students applying abridged DfE tools to analyse and make improvements to a range of products. A brief review of the DfE results, conclusions drawn from using this approach, and feedback from students, are given in the paper.

8. O' Connor, F., Blythe, D. and McEvoy, D., Analyzing Environmental Issues - A Case Study of a Product under Development, *Proc. IEEE International Symposium on Electronics and the Environment*, Chicago, U.S.A., pp. 249-254, (1998).

The aim of this case study was to systematically analyse the major environmental issues associated with the full life cycle of a business keyboard, from market through to end-of-life. From the analysis design improvements could be made which could significantly improve the products environmental performance. The study involved both quantitative and qualitative analysis of the key environmental issues using an abridged life cycle approach, which involved techniques such as flow diagrams, matrices, profiling and checklists. The environmental criteria, from which the product could be analysed under, were identified through consulting the major product stakeholders at each of the key life cycle stages. Some potential improvements were identified with a view to a long-term modification of the design. A summary of the results from the study is given, along with conclusions drawn and a brief discussion of planned further work.

9. O' Connor, F. and Blythe, D., Designing Environmental Concerns in to Products - A Novel Qualitative Life Cycle Approach, *Proc. IEEE International Symposium on Electronics and the Environment*, San Francisco, U.S.A., pp. 192-197, (1997).

This paper introduces a novel life cycle approach to designing environmental considerations into products. The approach consists of a qualitative Life Cycle Assessment (LCA) framework for both single and multiple life cycle electromechanical products. The LCA framework will consist of a 'body of knowledge' and a methodology for applying this knowledge to evaluate designs. It will be able to integrate quantitative and qualitative data, consider the views of all the life cycle participants and be implemented as part of a Concurrent Engineering (CE) structure. Details of a pilot study on a sample number of consumers, including users, are given. The study involved undertaking questionnaires and informal interviews to identify, rank and weight consumers key product requirements and environmental considerations. It also involved gathering of participants views on general environmental issues such as product take back, rental/leasing and willingness to pay extra for perceived environmental benefits. A summary of the results and conclusions drawn from this study are given with a discussion of future work planned.

10. O' Connor, F. and McLaren, J., Definitions of ECDM: Product and Process Implications, *Proc. IEE Colloquium on Environmentally Conscious Design and Manufacture*, CIM Institute, Cranfield University, U.K., pp. 6/1-6/4, (1997).

Environmental concerns play an increasingly important role in product and process design. One approach to reducing negative environmental impact is Environmentally Conscious Design and Manufacture (ECDM). In this paper ECDM is defined and an overview of implications for product and process design are discussed. The use of a MET matrix is introduced as a method to facilitate life cycle thinking. Potential opportunities resulting from the implementation of ECDM are also introduced.

Appendix C: Publication Titles & Abstracts

PAPERS SUBMITTED FOR PUBLICATION

11. O' Connor, F. and Hawkes, D., A Multi-Stakeholder Abridged Environmentally Conscious Design Approach, submitted to the Journal of Sustainable Product Design, September 2000.

Existing research has not yet sought to understand the role of stakeholders in Environmentally Conscious Design (ECD). New ECD approaches will have to be able to adapt and interface effectively with various stakeholders in the design and development process and over the life cycle of a product to ensure that both single and multiple life cycle issues are considered. The approaches will need to be able to assist in analyzing designs and suggesting possible improvement methods. This paper outlines the key findings from an exploratory multi-method research project into the role of stakeholders in ECD. The project resulted in a novel multi-stakeholder abridged approach with the data gathered from a range of stakeholders over the life cycle of a number of electromechanical products and their packaging. The research showed how successful ECD relies on the close co-operation and input of many different stakeholders both within and external to a company.

12. O' Connor, F. and Hawkes, D., A Novel Environmentally Conscious Design Matrix for Abridged Life Cycle Analysis Tools, submitted to the International Journal of Life Cycle Assessment, September 2000.

The role of stakeholders in abridged Environmentally Conscious Design (ECD) approaches to has yet to be defined. New approaches should be developed to be able to interface effectively with various stakeholders over the full life cycle and be able to be tailored to meet their needs to ensure that all the key environmental issues are considered at the design stage. A project investigating the role of stakeholders in ECD was undertaken which resulted in a novel multi-stakeholder-abridged-approach. The data was gathered from a range of stakeholders over the life cycle of a number of electromechanical products. One of the key objectives was to develop a novel ECD matrix for analyzing environmental impact. The matrix should take into consideration the views of a range of stakeholders on the key environmental issues for single and multiple life cycle products. Surveys (questionnaires and informal interviews) and a focus group were used to identify and weight the key environmental issues. The novel matrix approach that was developed can be used independently or as part of the multi-stakeholder-abridged approach. The approach is user-friendly and cost-effective and provides an efficient way of assessing a product, relying on the input and close co-operation of many different stakeholders both within and external to a company. It can be continually updated and tested on other product groups and industries.

13. O' Connor, F. and Hawkes, D., A Novel Approach to Selecting the Life Cycle Strategy for an Electromechanical Product, submitted to the International Journal of Industrial Ecology, September 2000.

Selecting a suitable life cycle strategy for a product is an extremely onerous exercise, which needs to be carried out as early as possible in the design process. Making decisions on the product life span, whether it should have a single or multiple life cycles, and what to do with it when it finally becomes obsolete requires knowledge that many companies, especially small and medium sized enterprises (SMEs) do not have the time or resources to attain. Life cycle assessment (LCA) techniques provide a useful step forward through considering the environmental impacts of every stage of the product's life, from design through to end-of-life. The restrictions of traditional LCA have been well documented and the abridged approach seems to be a more appropriate way forward for SMEs who require quick, cost-efficient and effective guidance. This paper outlines the findings from a research project, which through surveys (questionnaires and informal interviews)

and a focus group carefully examined a range of electromechanical products. Clearly defined stages were identified in deciding a suitable life cycle strategy that could be generically applied to a range of electromechanical products. This abridged life cycle strategy selection process is ideal for use and application by SMEs with limited resources and time providing a user-friendly and efficient way of determining a life cycle strategy at the design stage. This paper provides an overview of the process, and outlines the results from testing it on a mobile phone.